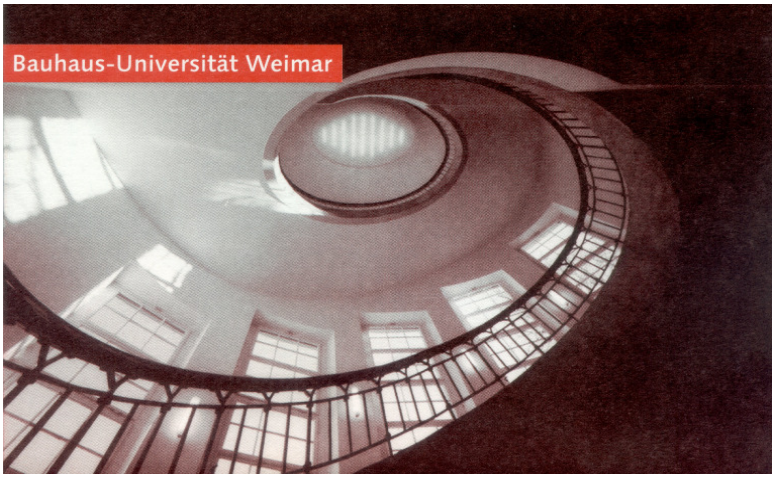
Construction Informatics Bauhaus University



A Flexible Model for Incorporating Construction Product Data into Building Information Models

A thesis submitted to
Bauhaus University in Weimar
For the degree of
Dr.-Ing.
by

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Date of Defense: 14th of March, 2006.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other University of learning.

Acknowledgments

I would like to thank my supervisors; Professor Karl Beucke for his invaluable guidance, sincere advice and encouragement throughout this thesis and Professor Berthold Firmenich for his invaluable support that enabled putting the theory of this work into a practical IT implementation.

I would like also to thank my colleagues Martin Freundt and Timo Heinrich who helped me with their advice and the material they teach at the Bauhaus University.

I am very thankful to Mr. Jens-Uwe Wagner, Mrs. Mechtild Bieber, our network and software administrators and Ms Christa Diez the secretary of the department for their support during the past three years.

I would like also to express my gratitude for the DAAD that enabled me to conduct such kind of research at the Bauhaus University in Germany. Last but not least, I would like to thank the ProSTEP AG company in Germany and the EPM Technology company in Norway for granting me an EXPRESS/STEP implementation course that helped me in using such technologies in this research work.

Dedication

To my parents and grand parents,

Abstract

When considering the integration and interoperability between AEC-FM software applications and construction products' data, it is essential to investigate the state-of-the-art and conduct an extensive review in the literature of both Building Information Models and electronic product catalogues. It was found that there are many reasons and key-barriers that hinder the developed solutions from being implemented.

Among the reasons that are attributed to the failure of many previous research projects to achieve this integration aim are the proprietary developments of CAD vendors, the fragmented nature of construction product data i.e. commercial and technical data, the prefabrication versus on-site production, marketing strategies and brand-naming, the referencing of a product to the data of its constituents, availability of life-cycle data in a single point in time where it is needed all over the whole life-cycle of the product itself, taxonomy problems, the inability to extract search parameters from the building information model to participate in the conduction of parametric searches. Finally and most important is keeping the product data in the building information model consistent and up-to-date. Hence, it was found that there is a great potential for construction product data to be integrated to building information models by electronic means in a dynamic and extensible manner that prevents the model from getting obsolete.

The study has managed to establish a solution concept that links continually updated and extensible life-cycle product data to a software independent building information model (IFC) all over the life span of the product itself. As a result, the solution concept has managed to reach a reliable building information model that is capable of overcoming the majority of the above mentioned barriers. In the meantime, the solution is capable of referencing, retrieving, updating, and merging product data at any point in time. A distributed network application that represents all the involved parties in the construction product value chain is simulated by real software tools to demonstrate the proof of concept of this research work.

Keywords: *Construction Product Data, IFC, BIMs (Building Information Models)*

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Chapter 1

1.1 Introduction

This thesis is concerned with linking continually updated life-cycle product data to a software independent building information model (IFC) all over the life span of the construction product itself. The work resulted in a flexible and reliable building information model that is capable of referencing, retrieving, updating and merging product data from its information sources throughout the product's value chain.

The thesis as a whole aims at designing a new solution concept that is based on the existence of construction product data, side by side in parallel to the Building Information Model has been established. The data can be retrieved by parametric searches as well as global unique identification throughout the product's overall life-cycle. The work takes into consideration the characteristics and peculiarities of the construction products' value chain. Furthermore, the product's information model is developed step by step with the product itself, as if it were one of its components. The concept distributes and allocates the responsibility of building the product information model among the parties that create and own the information themselves. The concept is proved and simulated by a real open network distributed platform application that represents all the parties involved in the construction product's value chain.

1.2 Aim and Objectives

1.2.1 Aim

- *"Linking continually updated extensible life-cycle construction product data to software independent Building Information Models, throughout the life-cycle of the product."*

1.2.2 Objectives

1- Viewing the literature and the state-of-the-art of linking construction product data to Building Information Models.

2- Identification of problems and key barriers that hinder the integration of continually updated product data with Building Information Models.

3- Putting forward some guidelines that can help changing the current status of lack of integrity of product data with Building Information Models.

4- Designing a new concept that overcomes the shortcomings of the previous research efforts according to the previously developed guidelines. In addition to taking into consideration the peculiarities of the construction product's value chain and its marketing strategies.

5- Identification of relevant IT technologies that can serve achieving the aim and objectives of this research work.

6- Providing a proof of concept through a real software development.

7- Independence from any proprietary commercial software applications or Building Information Models.

1.3 Methodology

The research work begins with a view of the literature and the current state-of-the-art of the

relation between electronic product catalogues and Building Information Models with the aim of providing a clear definition of the problem and putting forward some guidelines to be followed for the development of any solution concept.

The research views some of the marketing strategies that influence the construction products physical market place as well as the virtual market space (Internet), together with the peculiarities of the construction products' value chain.

In the light of the literature review and the analysis of the construction products' value chain, a new concept is suggested to overcome the identified key barriers and problems.

Finally, a proof of concept is provided through an open distributed software platform, that is independent from any proprietary software application to link construction product data with a software independent Building Information Model (IFC).

1.4 Scope

The developed solution is proved by implementing a longitudinal section throughout the suggested model. The software development covers construction products only, where as the main abstract concept is extensible and includes other aspects such as construction services. Some resources such as equipment, labour and so forth are considered to be out of the scope of this work. Moreover, an example of a wall, an opening and a door are only implemented in the Building Information model. However, the same concept can be applied for the rest of the spatial elements, e.g. slabs, columns or windows. In the meantime, taxonomy and ontology problems of construction products are not covered in this work.

It is also worth mentioning that the author is not a computer science specialist or an IT expert. The author has depended partially on attending courses for the basics of Java programming, CAD development, EXPRESS (ISO 10303-P11), EXPRESS-X (ISO 10303-P14) and STEP (ISO

10303 P-21) and partially on self learning skills. This proves that the technologies are not difficult to learn and that they are well documented.

1.5 The Structure of the Thesis

The thesis consists of two main parts. Part I- chapters 2,3,4 – is a view of the literature and the state-of-the-art of electronic product catalogues, an identification of key barriers and problems that prevent the integrity between product data and Building Information Models as well as an analysis to the construction product's value chain and marketing strategies and finally a design of a new concept for a solution that tries to overcome the barriers that were identified in the previous stages.

Part II- chapter 5 – provides a proof of concept to the designed solution. It simulates all the parties that are involved in the construction product value chain according to the solution's concept. It also includes a set of developed software tools that are capable of carrying out different processes on the IFC model. Among these process are mapping, merging and updating of product data to the IFC model.

Chapter 2- "Literature Review", comprises the state-of-the-art of the linking between electronic product catalogues and Building Information Models on the scale of commercial product catalogue vendors, initiatives from major CAD vendors and finally independent research projects.

Chapter 3- "The Statement of the Problem", provides an analysis of the value and supply chains of the construction products and investigates the roles of marketing strategies and information middlemen in the value and supply chains. It also discusses the peculiarities of the construction products with a special emphasis on the prefabrication versus on site fabrication. Moreover, It discusses the need for life-cycle information and the different search mechanisms that are used for searching for construction products on the Internet. It ends with a discussion about the

integration of product data with Building Information Models together with putting forward some guidelines that are used in the development of the solution concept.

Chapter 4- "Model of Proposed Solution", introduces a new concept called OIP (Object Information Packs) as a suggested solution. It begins by defining the concept, allocating the responsibilities of the production of such information packs and then moves to the technical definition of the data management system and its structure. The chapter provides a discussion of the basic concepts, examples and scenarios of use.

Chapter 5- "Prototype Implementation", provides a proof of the solution concept provided in chapter 4. It is a direct implementation to the information model that is defined in the previous chapter. It makes use of the IFC2x model as a software independent Building Information Model. It simulates the roles of suppliers, manufacturers and clients (users) in real life scenarios. It provides database management systems, software tools that provide functionalities for mapping, merging and updating information inside the IFC model. Furthermore, these tools enable the specification of product parameters in addition to the extraction of query parameters from the CAD/IFC model. Moreover, they enable the conduction of parametric searches and monitoring the existence of any new updates to the products' data.

Chapter 6- "Conclusions and Recommendations for Further Research", presents the main conclusions of the whole study and points out some areas for further research. Furthermore, it puts forward some guidelines for the development of the solution concept that has been suggested throughout this study.

Appendix A1: Is an example of a STEP ISO 10303-P21 file that shows the main components of a STEP-P21 file and their functionalities.

Appendix A2: Is a "jj" doc output of the grammar of the developed STEP parser.

Appendix A3: Is the IAI definition of the PsetDoorCommon property set

Appendix A4: Is the Java Code for the property set PsetDoorCommon

Appendix A5: Is an example of an exported STEP-P21 file from the author's software.

Appendix B: Is a UML diagram that shows the use of a Drag and Drop solution over the Internet for the mapping, merging and the transfer of data.

Appendix C: Is a CD-ROM that contains the Java coding, Databases, testing IFC/CAD models, and video demonstrations for the prototype development.

Chapter 2

Literature Review

2.1 Introduction

The aim of this research work is to try to keep BIMs (Building Information Models) up-to-date and capable of providing accurate information about their construction products without being limited to its original information content. This is envisaged to be achieved by making an on-line source of life cycle multidisciplinary information available for any information need that might arise to any application using the model. The latter extends the activities of the model beyond its information content and in the meantime does not overburden the model with information that is not needed or used at a certain stage in the life cycle of the product. Moreover it makes information updates for dynamic properties such as the current commercial and business aspects available on-line for the model, i.e. It prevents the model form getting obsolete.

An example of this is a simple door. Its geometry is defined by CAD, an energy simulation programme needs to know its thermal transmittance coefficient, a cost estimating tool needs to know its up-to-date price, a contractor needs to know its availability at a certain point in time and later the facility manager needs to know the specifications or the name of the supplier of a certain spare part of the door.

It is obvious that architects or any other practitioners working on a project that contains thousands of elements would not have the resources to model each element in the project. They are most probably paid for the production of printed drawings and documents rather than models. The problem is even worse when we consider the fact that these models could be project specific and may not be reused in a product library for similar projects. This approach would

most probably go beyond any approach for return on investment employed. Hence, it is a task that would be best undertaken by manufacturers and suppliers, where most of the modelling information is usually available in their product catalogues. This directs the research work towards studying previous research that is done in the area of electronic product catalogues and on-line product libraries.

2.2 The state-of-the-art of on-line product catalogues

By researching the area of electronic product catalogues, it was found that the main efforts could be categorized into three main categories:

1- Commercial product catalogue vendors.

2- Independent initiatives from major CAD vendors.

3- Research projects ranging from individual researchers through to large-scale European and international projects.

2.2.1 Commercial product catalogue vendors

The majority of commercial product catalogues vendors have developed their own national on-line systems that are text based[1], where they are searched according to keywords (names of products, suppliers or manufacturers) or local classifications systems and standards. The user is usually able to navigate through categories of the searched product or the catalogue of a certain manufacturer or supplier. The user can also browse through the multimedia representation of the product and try to get relevant information about the product.(Timm and RoseWitz 1998) In most of the cases the information is delivered in the form of a PDF document that is extracted from the originally paper-based catalogue, where product information is presented in the form of text and pictures. Researchers like (Amor et al 2004) have the view that the majority of electronic catalogues, even today, have duplicated the paper paradigm of the original paper based catalogues, and as a result, there is an inevitable need for human interpretation and transcription

1 Example: HTML and PDF files

of information from the catalogues to other software tools. Furthermore, the parametrised information that could impact the selection of products must still be manually interpreted.

Country	***Name***	***URL***
Australia	AEC Data Link	http://www.aec.com.au/
Canada	AEC Info Centre Product Library	http://www.aecinfo.com/
Italy	Aedile	http://www.aedile.it/
USA	Architects First Source Online	www.firstsourceonl.com/
Thailand	Architecture Products Asia	http://www.aecasia.com/
Norway	BA-torget	http://www.bygg.no/
Germany	BauNetz	http://www.baunetz.de/arch/
UK	Barbour Index	http://www.buildingproductexpert.co.uk
UK	Better Build	http://www.betterbuild.com/
Australia	BUILdata	http://www.buildata.com.au/
USA	BuilderNET	http://www.seeq.com/
USA	BuilderNeeds	http://www.buildersneeds.com/
UK	Building Information Warehouse	http://www.biw.co.uk/
UK	Building Products Index	http://www.bpindex.co.uk/
Sweden	Byggsverige	http://www.byggsverige.com/
Japan	E-CALS	http://www.ecals.cif.or.jp/outline.html
India	FindStone	http://www.findstone.com/
Finland	FIMKO	http://www.fimko.fi/
Finland	Insinoori.net	http://www.insinoori.net/
UK	Interior Internet	http://www.interiorinternet.com/
Finland	Progman	http://www.progman.fi/
Finland	Rakentaja Foorumi	http://www.jyda.fi/
Australia	Spec- Net	http://www.spec-net.com.au/

Country	***Name***	***URL***
USA	Sweets	http://sweets.construction.com/
Switzerland	Swiss Internet Baubank	http://www.dewadata.ch/baubank/
UK	Virtual- Engineer	http://www.virtual-engineer.net/

Table 2.1 Commercial e-Catalogs

After performing text searches and examining the catalogues stated in table 2.1, it was found that parametric searches according to properties are not yet supported (Construct IT 2004) and furthermore, the product information is not by any means reusable for any design purpose and consequently has to be manually re-keyed.

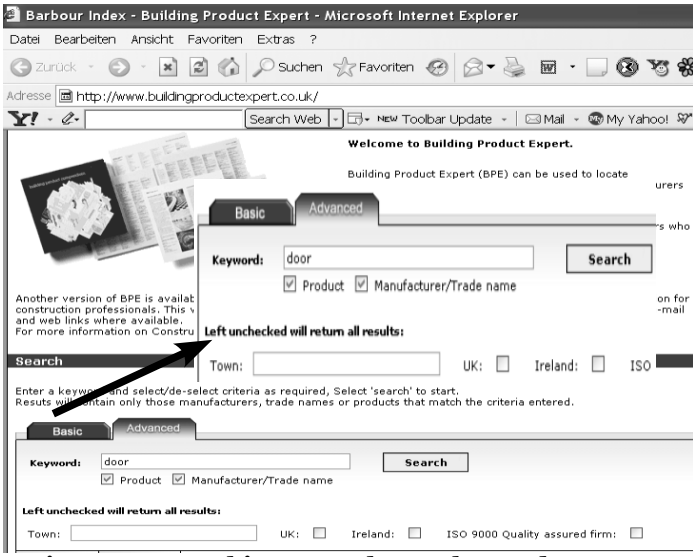


Figure 2.1 Searching e-Catalogues by Product Name

As a sample example of these e-catalogues is the Barbour Index in England found at

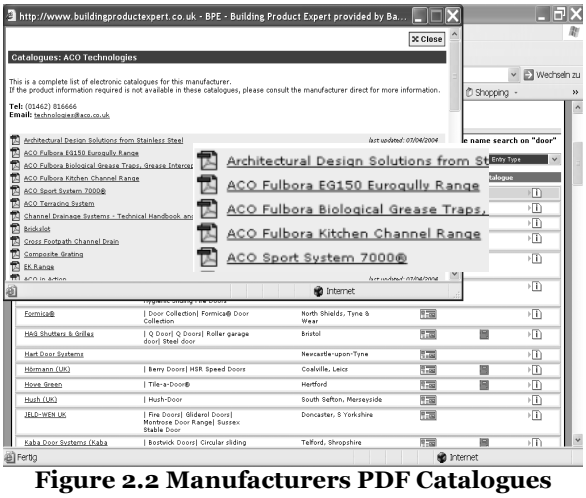


Figure 2.2 Manufacturers PDF Catalogues

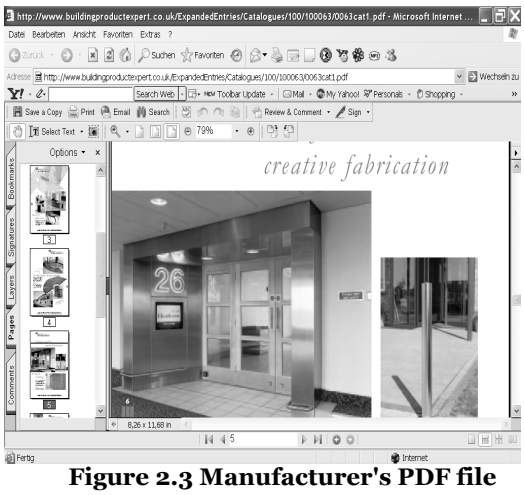


Figure 2.3 Manufacturer's PDF file

(http://www.buildingproductexpert.ac.uk). By carrying out a simple search the word 'door' was entered to the search field. As it can be seen from figure 2.1, the website allows searching the

catalogue by entering a product name or a manufacturer trade name. The author got two forms of search results; the first is a list of door manufacturers and the second is a list of door categories, example: wooden doors, aluminium doors and so forth. By following the links to door manufacturers, it ended up to PDF files shown in figures 2.2 and 2.3, replicating the paper-based catalogue. However, by following the links to a product category, it ended up with an HTML page showing the address of a supplier, figure 2.4.

By examining other e-catalogues, it was found that the Barbour Index is a representative sample to what is offered by the others. It is nearly the same at the end of the hyper links; HTML or PDF files and the search mechanisms depend on textual keywords and rarely on any structured information. Hence, product information is not by any means reusable for any design purpose and consequently has to be interpreted by humans and manually re-keyed.

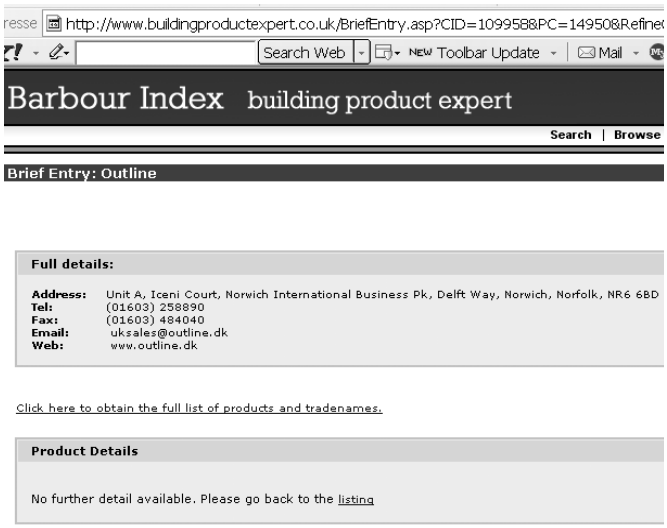


Figure 2.4 Supplier's Details

2.2.2 Independent initiatives from major CAD vendors

CAD vendors have also been trying to support access to product information within their own software environment and proprietary file formats. Among these trials are the ones by ArchiCAD (Graphisoft 2004) and Architectural Desktop (Autodesk 2004). The coming section discusses both of them with a special emphasis on the GDL (Geometric Description Language) from Graphisoft and the i-drop technology from Autodesk.

2.2.2.1 Architectural Desktop

The Autodesk i-drop[2] technology claims to enable the association of data files, such as pricing information, order forms, design information or manufacturer product details, together in the same i-drop data package, that is linked to chosen CAD blocks in a CAD environment by a drag-and-drop operation from a web site. In other words, the i-drop content is created for the AutoCAD Blocks, then the i-drop definition is tagged with the source URL or any other web location and inserted to an HTML page. However, at the end, the selection process is still done through whatever navigation that is supported by the web site hosting the information. An example of such i- drop web page is shown in figure 2.5. (Autodesk 2004)

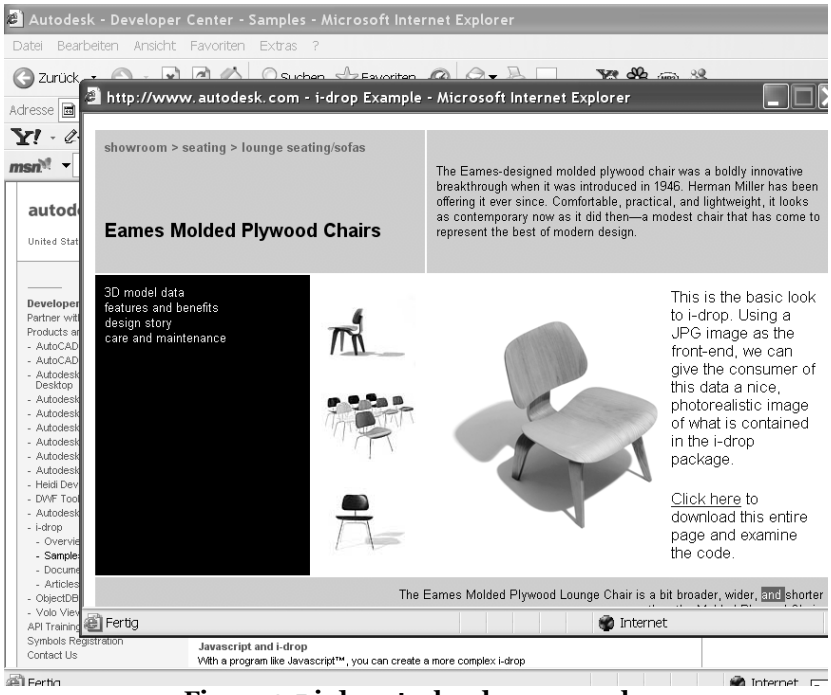


Figure 2.5 i-drop technology example

2.2.2.2 ArchiCAD

The Graphisoft efforts are focused on its GDL technology (Geometric Description Language). It allows users to create their own CAD objects using a scripting language (GDL) that resembles the BASIC language to a great extent, a GDL sample is shown in figure 2.6. The same figure also shows how the user can provide a 2D script that presents the object in 2D, and a master script for defining parameters that are used by both the 2D and 3D scripts (Nicholson-Cole, 2000). Figure 2.7 shows the data types supported by the GDL scripting language such as: length (dimension),

2 The Autodesk i-drop technology is an XML based technology created for software developers and programers to enable them to create Web pages containing design content that can be dragged and dropped into an i-drop capable Autodesk product. i-drop technology, at http://usa.autodesk.com

angular measure, natural numbers, Integer, Boolean, String, Material, Line Types, Hatching Patterns, Line Colour and so forth.

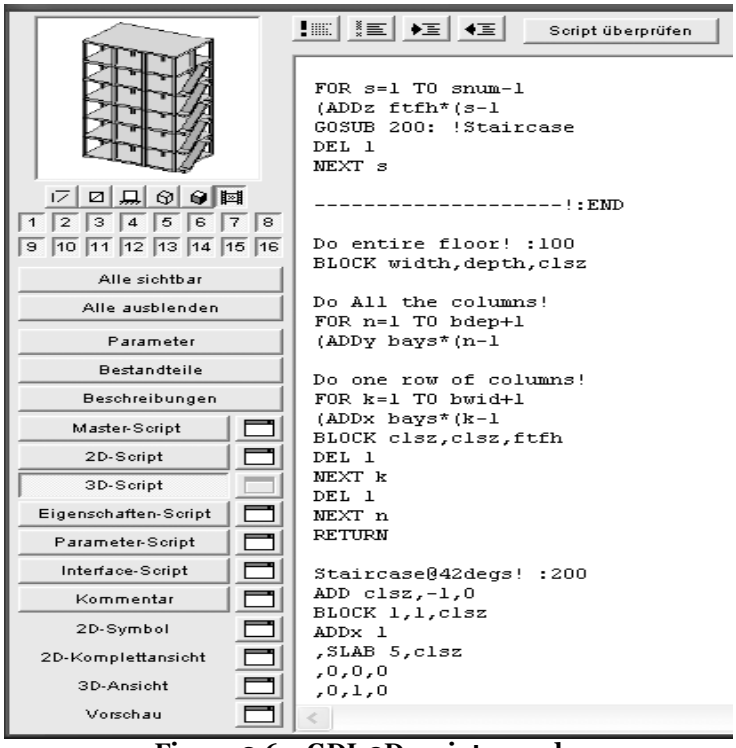


Figure 2.6 a GDL 3D script sample

Electronic product catalogues like GDL central (http://www.gdlcentral.com/) or ArchiForum (http://www.archiforum.de/) offer their products in a drag and drop environment to ArchiCAD users and through an add-on adaptor to Autodesk's Architectural Desktop and other major CAD software users.

However, it should be mentioned that, the GDL object models work best inside a Graphisoft Environment and have inevitable loss of information when transferred to other CAD environments. Nevertheless, GDL is a proprietary extension of Graphisoft and is not independent from its environment. The author has also discovered the fact that the GDL parameters are not contained in other exports formats like IFC (tried with ArchiCAD version 7.0, student version and IFC2x add-on). Furthermore, the capability of users to define their own object parameters, without following any standards, leads to the fact that

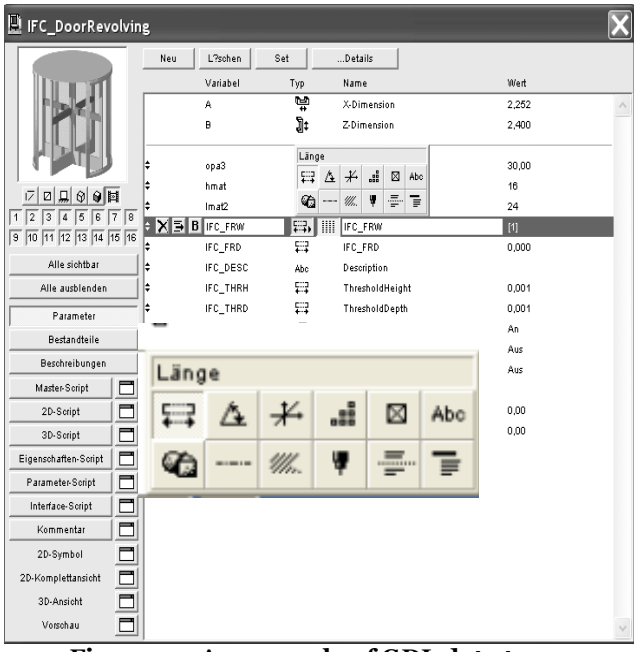


Figure 2.7 An example of GDL data types

these parameters are more often than not incapable to help conducting parametric searches for products or transferring data across different software systems, AEC disciplines and national boundaries.

2.2.3 Research Projects

There have been many research projects in the field of electronic product catalogues and product libraries, ranging from individual researchers to large-scale European and international projects. There are links to more than two hundred and sixty EU projects found under the VTT's (Technical Research Centre of Finland) website: http://cic.vtt.fi/links/euproj/index.html .

Despite the fact that all the projects are in the same field, every research initiative addresses the problem with different aims, views and priorities. For example, there are projects that focus on the taxonomy part of the problem i.e. the taxonomy of product properties and mapping them from one language to another as an essential base for communication of meaning and hence conducting parametric searches. An example of such research projects is the *eConstruct* project. Other projects focus on the exchange of product data in independent formats like XML, an examples of these types of projects are the ifcXML and aecXML projects. The latter more often than not necessitates the mapping of EXPRESS – ISO 10303 P-11 and the IFC model to XML schemas. However, none of the research projects has proved any dominance on the other or any outstanding practical implementation. This might be attributed to the existence of differences in national standards, classification systems and languages. Furthermore, the process of mapping EXPRESS to XML is not an easy task, bearing in mind that EXPRESS is a strong modelling language that is capable of imposing a lot of constraints and rules on its objects, while on the other hand the XML capabilities in such a domain can not be compared.

The coming section tries to address outstanding research work that can help direct this research work towards rectifying failures and filling gaps that were not covered by the previous work. It focuses on the analysis and description of a number of research projects that address the problem of product libraries and electronic product catalogues from a point of view that is focusing on

both linking product data to BIMs and conducting parametric searches.

2.2.3.1 ARROW

ARROW is a three years UK initiative project funded by the PiT programme. Its main aim is to retrieve manufacturer's product information from the so called virtual warehouses. It claims that it allows manufacturers to describe the attributes of their own products and link them to a virtual warehouse that is able to handle structured as well as unstructured (free text) information from suppliers and manufacturers. Furthermore, manufacturers should be able to upload any kind of electronic documentation that is related to the product. In the meantime, responses to queries should be in a form that can be used by CAD systems. It should be mentioned that the ARROW model is built entirely upon the IFC model, where one hundred and eighty tables were created in Microsoft Access database. These tables act as a mapping of the IFC model, in addition to some extensions to cover the full range of product information.

The process of mapping ARROW's object oriented model into a relational database, has highlighted many of the problems of representation of object oriented data structures in a relational database technology. The problems were attributed to the lack of polymorphic capabilities in a relational database as well as the representation of aggregate types (lists, sets, bags, arrays, etc.). Furthermore, SQL queries that are needed to retrieve records from the database usually consist of extremely long WHERE clauses and more often than not arises the need for multiple sub-queries.

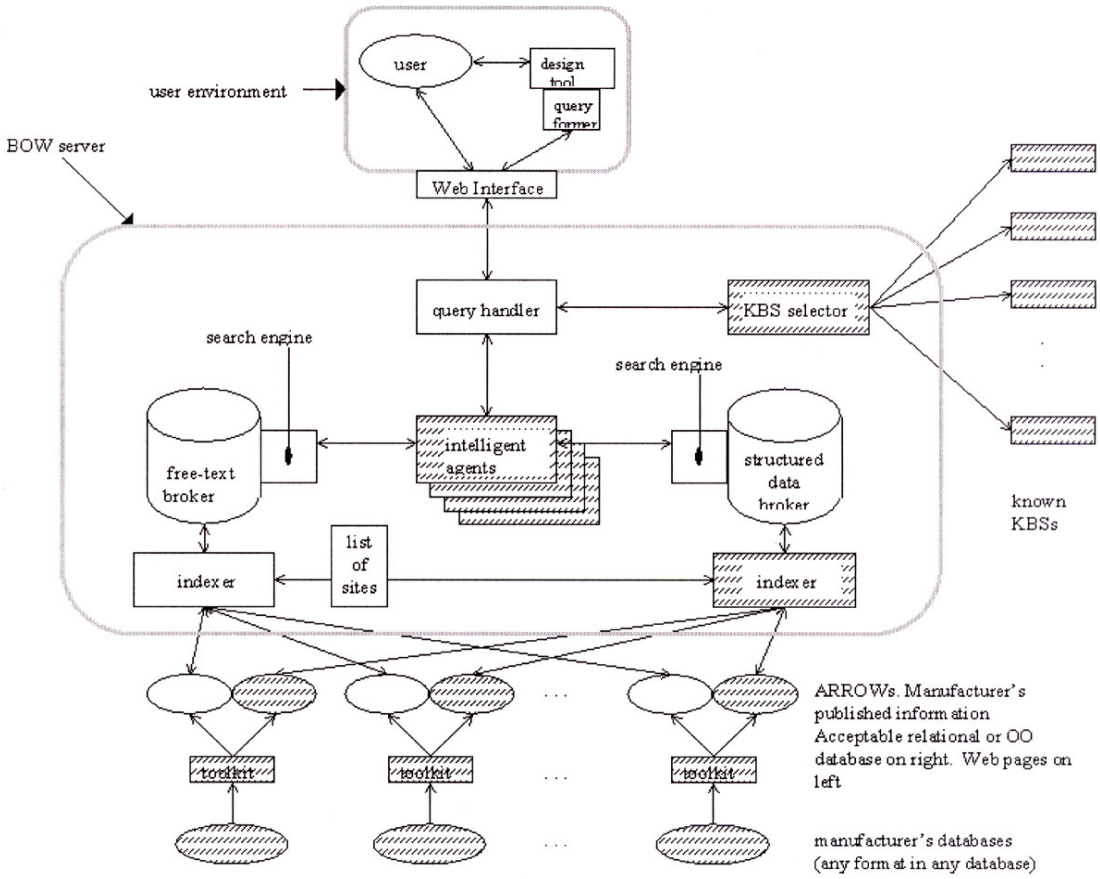


Figure 2.8 The Structure of the Arrow System, (Newnham et al 1998)

As shown in Figure 2.8, the ARROW systems consists of three main parts. First is the user, who has the possibility to connect to the BOW (Building Object Warehouse) server. Second is the BOW server and third is a number of distributed product databases that contain product data on the Internet in a variety of formats.

According to (Newnham el al 1998) ARROW is envisaged to be implemented in two main scenarios: The first scenario is the retrieval of a DWG file and dropping it into an AutoCAD drawing. This is implemented by a short AutoLisp programme that extracts parameters from a CAD object and sends them to another programme on the client machine. This programme connects to the search engine (on the BOW server) and sends a query. The search engine returns a product that fitted the dimensions given in the drawing and for which there is a DWG available. The AutoLisp programme displays the results of the search and asks the user if he wishes to replace the object with the real product drawing. However, this scenario does not support free

text searches .The second scenario uses a web browser interface to demonstrate the blending of the text and structured database searches; where the user selects from a list of products and then is introduced to a list of searchable fields representing the properties of that product.

2.2.3.2 CONNET (CONNstruction information service NETwork)

The CONNET project (www.connet.org) is a one year EU funded project, that tried to achieve the following objectives:

- Enabling queries to be passed between European national systems to provide a European-wide identification service.
- A data model that helps catalogue producers migrate the current paper-equivalent on-line systems to complex attribute driven services.
- Providing a service-based infrastructure for basic support to new catalogue producers. (Amor et al 2000).

2.2.3.3 Eindhoven University of Technology

Research work at the Eindhoven University has tried to achieve a feature based modelling approach for product representation and dynamic specifications of differentiating features for products, in addition to the management of product information across firms and projects. (Van Leeuwen and Fridqvist 2002).

2.2.3.4 GEN Projects

PROCAT-GEN (Cook et al 1999, Faux et al 1998) and GENIAL (Debras 2000, Faux et al 1998) are three years EU funded projects. They tried to develop an open XML-based data model for product classification and attributes of products. Further more, it provides manufacturer's and suppliers with side tools to enable searching for products within product catalogues. The right to carry out information updates is also granted to particular users.

2.2.3.5 Georgia Institute Of Technology

The research work at Georgia Institute Of Technology focuses on using performance criteria and conducting virtual experiments on products as a means of product selection. (Jain and Augenbroe 2003). Candidate products from suppliers and manufacturer's databases are substituted in the experiments, tested and ranked according to their performance in the virtual experiment. The user is also able to chose a range of performance indicators and apply different weights to them. In other words, products are ranked according to the results of pre-defined parametric simulations that assess the performance of a selected product in a user defined design context, i.e. quality of performance rather than specifications and decision making process rather than a decision taking process.

The author will refer to this work later because of its dependence on extracting contextual

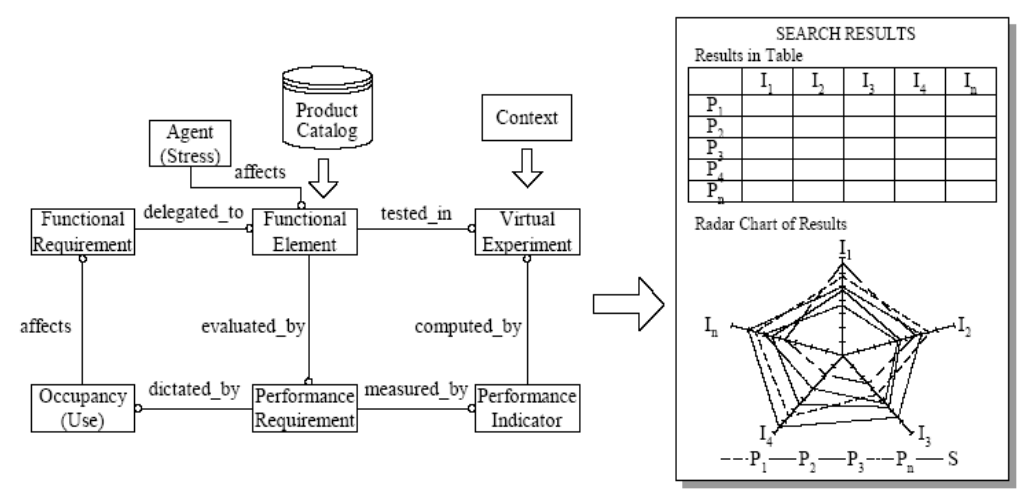


Figure 2.9 Performance based Searches (*P: Product, I:Performance Indicator, S:Standard/Code*), Source: (Jain et al 1998)

information from the building model. The virtual experiments take place under the BIM's parameters in order to reach the ranking of a product according to certain circumstances rather than criteria like price, material weight or physical dimensions. Moreover, the virtual experiment

is in itself a parametrized building model that can be instantiated at any time with values of the current design context and parameters of the candidate product.(Jain et al 2003)

Figure 2.9 shows relations between various performance indicators, the virtual experiment, the context of the model and the product catalogue . The virtual experiment extracts its attributes from the BIM context and a set of performance indicators are defined, upon which the ranking of catalogue candidates takes place. The right-hand-side figure shows how the results can be tabulated and ranked on a radar chart.

2.2.3.6 Loughborough University

The research work at Loughborough University is focused on an agent based approach to gathering and querying product data from XML-based repositories, also an algorithm for interpreting standard data in PDF documents, in addition to an agent-based automated purchase negotiation system were developed. (Obonyo et al 2001)

2.2.3.7 University of Edinburgh

The research work at the University of Edinburgh (Ofluglu 2003, Coyne et al 2001) focuses on the design side and supporting the interaction with on-line product information. It looks at the problem from an architect's and quantity surveyor's point of view in a sense that considers that product selection is based on records that are kept of favourite products that were used repeatedly on different projects, i.e. a case-based aspect to product selection. Thus, the research work adopts what is called a pointer management policy, where URLs for construction products are arranged like bookmarks relevant to a CAD project in the form of icons on a Java window, as shown in figure 2.10.

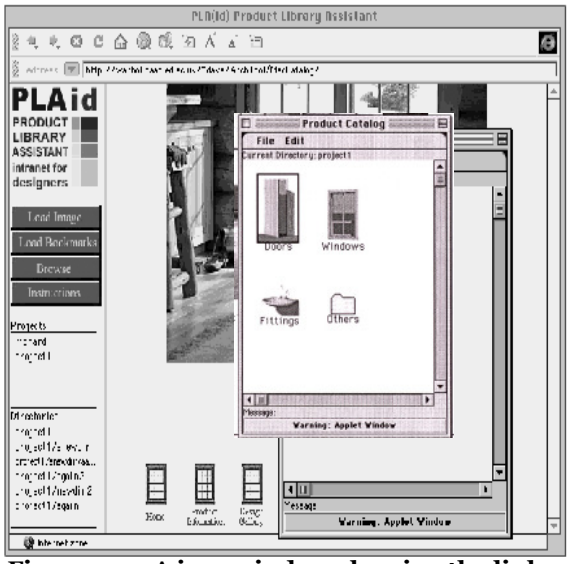


Figure 2.10 A java window showing the links to Web pages, Source: (Coyne et al 2003)

Another application is the extraction of design parameters from CAD models. A parser was built to parse the documentation output of ArchiCAD schedules, figure 2.11, and consequently write them to a relational database.

Finally, the research builds a scenario of use on the envision that CAD system developers are adopting the initiative of making their software *"network aware"*, where the CAD system is linked with an independent CAD system development site that maintains product information and keeps it up-to-date, in addition to reporting any updates. The research work emphasizes that software developers like Autodesk and Bentley are seriously considering the above-mentioned initiatives and therefore, extending the web facilities of AutoCAD and MicroStation (Coyne et al 2001).

17ScotlandSt.List1

	B	C	D	H	I	J	K	L	S	T	U
1	KIND	NAME	NUMBER	PEN	LAYER	WIDTH	LENGTH	HEIGHT	ADDITIONAL		PARAMETERS
2	DOOR	D1 -Tr	2	3	Exterior walls	0.9		2.1		63.5	19.1
3	DOOR	D1 -Tr	5	3	Exterior walls	0.9		2.1		63.5	19.1
4	DOOR	D1 -Tr	1	3	Exterior walls	0.9		2.1		63.5	19.1
5	DOOR	D1 -Tr	4	3	Exterior walls	0.8		2.1		63.5	19.1
6	DOOR	D1 Transom-Tr	1	3	Exterior walls	0.9		3		19.1	63.5
7	DOOR	D1 Transom-Tr	1	3	Exterior walls	1		3		19.1	63.5
8	WINDOW	W DoubleHung	5	3	Exterior walls	1.2		2.4	38.1	50.8	44.5
9	WINDOW	W DoubleHung	1	3	Exterior walls	0.6		1.4	38.1	50.8	44.5
10	OBJECT	Barcelona Chair	1	4	Moveable Furniture	0.8	0.8	0	25	11	
11	OBJECT	Bathtub-Regular	1	4	Furniture & Equipment	1.8	0.8	0	500	22	381
12	OBJECT	Bed 1	1	4	Furniture & Equipment	1	2	0			
13	OBJECT	Cab B-P 1D	2	4	Furniture & Equipment	0.6	0.6	0	2300	3	600
14	OBJECT	Cab Base 1D	2	4	Furniture & Equipment	0.6	0.6	0	900	3	38.1
15	OBJECT	Cab Base 1D	1	4	Furniture & Equipment	0.1	0.6	0	900	3	38.1
16	OBJECT	Cab Base-MultiDrawer	1	4	Furniture & Equipment	0.6	0.6	0	900	3	38.1
17	OBJECT	Cab Sink 2D-Drawer	1	4	Furniture & Equipment	1.1	0.6	0	900	3	38.1
18											
19											

17ScotlandSt.List1

Figure 2.11 A schedule of Components as produced by ArchiCAD

2.2.3.8 GAEB

GAEB (www.gaeb.de) is a holistic approach for information exchange in the German building and construction industry. GAEB itself is the Joint Committee on Information Technology in the German construction industry. The public and private owners, architects, engineers, suppliers, research institutes and construction software companies are all represented by their own federations or professional associations in GAEB. It has developed an XML standard (GAEB DA 2000-xml) that is aimed at providing an information infrastructure that covers the needs of the industry. The standard covers the range of documents starting from the first request for bids till the delivery of construction material and elements from suppliers and manufacturers to the contractor and billing of the services. Furthermore, a common set of rules for optimisation and value creation are defined and made available to users for free.

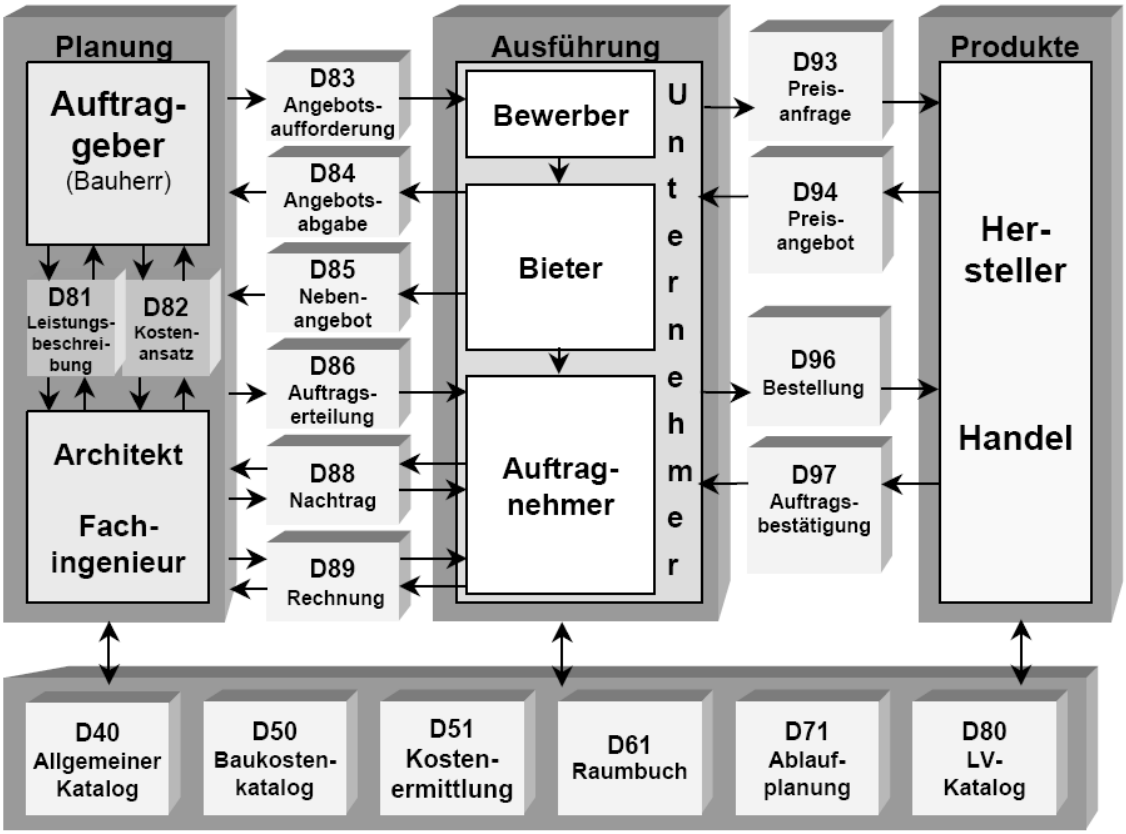


Figure 2.12 Information Flow in GAEB DA2000-XML Standard, (Diaz, 2004.)

Figure 2.12 shows the holistic information flow and how the communication between different parties take place through XML documents, where each document type has its own DTD (Document Type Definition) . Each document is assigned to a so called data exchange phase, e.g. the data exchange phase D83 shown in figure 2.12 represents the call for bids. Additional information is accumulated during various phases of the project. However, the information must be available in the assigned construction sequence, in addition to using the specific document type for each exchange phase (Diaz 2004).

The main scenario of use implies that a bill of quantities or materials is used for data exchange between construction companies and manufacturers, dealers or suppliers. The contractor receives the bill of quantities and sends its information in turn to manufacturers, suppliers or dealers, where he gets back a quotation. The contractor modifies this information and incorporates it in his estimate and uses it for the bidding process.

However, it should be mentioned that the information exchange process in all stages can not be successful without the existence of an exchange standard that is capable of being handled by various software and hardware platforms, in addition to providing a common language for construction information exchange. The latter was considered to be the main challenge for GAEB. Hence, the standardisation was done on two levels: First is on product catalogue structures and second is on product classification. At the catalogue structure level the BMEcat-format (www.bmecat.org) has been used. Consequently, any supplier must comply his catalogue with the BMEcat standard. On the other hand, on the classification level, in order to avoid each supplier using his own vocabularies and structures in describing his product, the (*eCl@ss 2004)* standard was implemented.

2.2.3.9 RINET -Building Product Database

RINET is a three years project funded by the Finish Vera Programme. Its main declared objective is to implement a prototype building product library on the Internet. It should be able to allow manufacturers to describe attributes of their products and to upload any related electronic documents, in an attempt to link structured product data with unstructured textual information from web pages and documents.

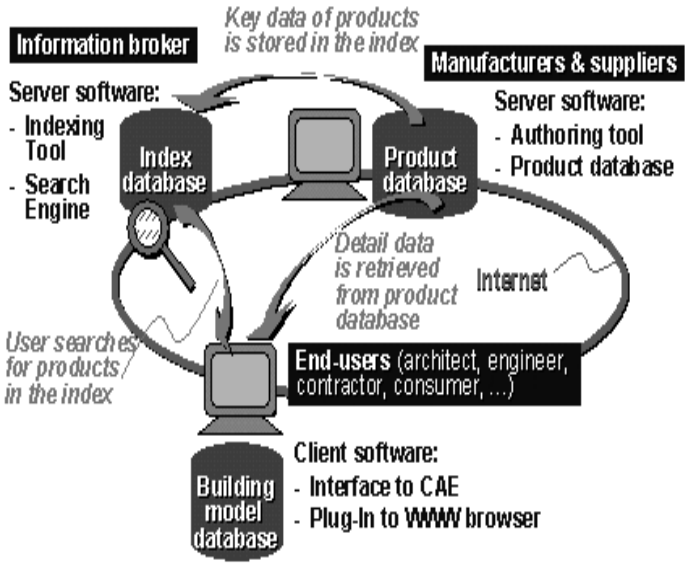


Figure 2.13 RINET'sConceptual Framework, Source: (RINET 2000)

Figure 2.13 shows the use of a central service on the Internet to maintain an index database that refers to information stored in distributed manufacturers' and suppliers' databases and websites. The index can be searched by three methods, first is by product properties, second is by

classification and third is by free text keyword searches. The project claims also that it is capable of reusing parametric product data through an interface to CAE. However, it should be mentioned that the client interface is built on the Finish Building 90 classification system. (Building 90 1999)

2.2.3.10 eConstruct

The aim of the EU IST-10303 *"eConstruct"* project (www.econstruct.org) was developing an XML vocabulary and grammar for the European BC (Building and Construction) industry, with focus on the communication of meaning by trying to overcome barriers that stem from differences in languages and national classification systems, i.e. the things that define the BC semantics. One partner of the project is the Dutch Specification Institute STABU (http://www.stabu.nl) which has an active role in the ISO/DPAS 12006-3 ("A frame work for object oriented exchange in BC"). STABU was considered to be the corner stone for developing the bcXML compliant taxonomy (the Lexicon).

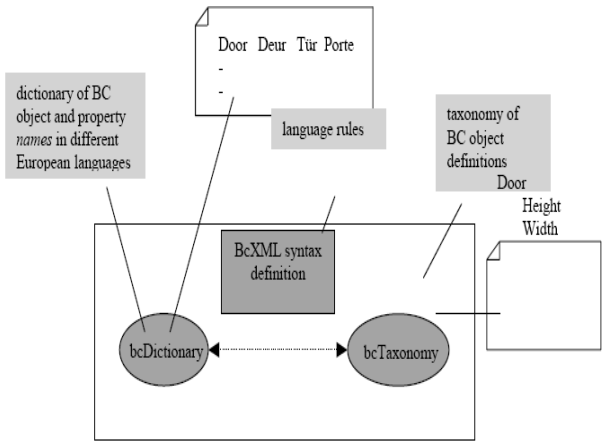


Figure 2.14 Main Constituents of bcXML, Source: (Tolman et al 2001)

Figure 2.14 shows that the bcXML consists of three main components: First is the bcDictionary for mapping names in different European languages, second is the bcTaxonomy for holding the main objects and their attributes and third is the bcXML meta model that defines the language syntax.

Due to the fact that the eContruct project is not able to provide a complete dictionary in all

European languages, a limited set of words were developed in a limited set of languages in an open system that can be extended by others with additional words and translations. Hence, the aim was directed towards encouraging everybody to use bcXML compliant taxonomies so long as the produced XML documents conform to the bcXML rules (schema).

Finally, a set of developed prototype applications that use bcXML were developed. They depend on formulating queries from clients to suppliers in XML that complies with the bcXML schema. On the other hand responses to queries are returned in the same information format, i.e. clients can make use of the information by parsing and interpreting the XML file according to the definitions in the bcXML schema.

2.3 Conclusion

This chapter has examined forms of product information , selection mechanisms, queries to product information and forms of query results in different commercial, major CAD vendors initiatives and different scale research projects.

Commercial product catalogue vendors have proven to be oriented towards a free text HTML or PDF content that is searched by keywords. Moreover, the content is not reusable for design purposes and is not in a format that can be mapped to a building information model.

At the CAD vendors level the i-drop technology from Autodesk and GDL technology from Graphisoft were examined. It was found that the product selection process is still done through whatever navigation that is supported by the web site hosting the information. Furthermore, i-drop and GDL models are proprietary commercial developments and the transfer of any of them to a foreign environment results in inevitable loss of information and functionalities. On the other hand the freedom of structuring data about product properties without following any standards has led to the fact that these parameters are unable to communicate their meaning across different software applications and thus, incapable of conducting parametric searches .

Project	***Central Search Engine***	***MXL Communica-tion***	***Web access***	***Client User Interface***	***Taxonomy Standard***	***Linking to CAD***
ARROW	●		●	●		●
CONNET	●		●			
Eindhoven	●		●			
GEN	●	●				
Georgia						
Loughborough	●	●	●	●		
Edinburgh	●	●	●	●		●
GAEB	●	●			●	
RINET	●		●	●		
eConstruct	●	●	●		●	

Table 2.2 Features of Research Projects

By looking at table 2.2, there are some common features that were found in the majority of the research projects. The next sections discusses these features in relevance to the projects with the aim of putting forward some guidelines for the research work.

2.3.1 A central Database

It could be noticed that a central search engine or a central database is essential for the majority of the research projects. In most of the cases it plays the role of the index or pointers manager, where it directs queries to websites containing the required product information. In other cases it acts as a repository or a warehouse for product data. As a conclusion, whatever the role is, it is essential to have a single focal point that organises the communication between different parties. Furthermore, it has been proven that client interfaces alone are not able to conduct parametric queries without the existence of a central body that can interpret queries and re-direct them.

2.3.2 Communication in XML

Many of the research projects have tried to communicate through predefined XML schemas that represent a vocabulary for communicating meaning. Although, XML has its advantages, product information transfer can still be conducted by other means, e.g. STEP ISO 10303-P21 files. Specially if we consider that product data in most of the cases is already defined in EXPRESS and exchanged in STEP. Moreover, developing XML schemas usually involves mapping EXPRESS definitions to XML schemas. However, the XML language gives the possibility of defining properties in different languages and hence, solving part of the taxonomy problem, in addition to its software independence and ability to be visualised on web browsers. Nevertheless, one of the disadvantages of XML is the size of the files. The author transferred a STEP file to an XML document and it grew seven times in size. Another disadvantage might be its incapability to fully model rules and constraints defined in the EXPRESS language. With the existence of STEP ISO 10303-P21 parsers, the problem of the ability to communicate STEP across the Internet becomes of less importance.

2.3.3 Access on the web and client user interface

Almost every research project has tried to implement both a web interface and a client tool in parallel to each other. In most of the cases the web interface is used for conducting queries, while the design or client tool is used for incorporating product data into the CAD environments (e.g. ARROW and the research at Edinburgh University). However, it has not been seen any trial to map the product information to a software independent building information model, although there are projects that mapped the IFC model to a relational model on a relational database (ARROW) just for keeping product data, but there was no sign of mapping this data to an existing IFC model at the client's side by the client interface.

2.3.4 Taxonomy and Standards

Projects like eConstruct (bcXML), GAEB (DA 2000-xml), aecXML, ifcXML and so forth have

tried to create their own syntax and definitions of standards through the development of XML schemas that they thought could satisfy the communication needs for the transfer of information from one party to another. However, no one schema could prove any dominance on the other. Each has to serve certain domains and local construction markets that are different from the others. In addition to the role played by the quality of mapping EXPRESS ISO 10303-P11 standard to XML schemas.

2.3.5 Linking to CAD

It has been noticed that projects that tried to make use of product information have tried to incorporating the data to CAD environments e.g. AutoCAD by ARROW and the University of Edinburgh. Most of these trials were made using AutoLisp, where the geometry of the real product replaces the symbol of the designed product as an AutoCAD block. This block usually has a URL to a manufacturer's or supplier's website, where information in electronic documents like PDF or HTML pages can be found. This can by no means solve the problem of incorporating product parameters that can help multidisciplinary applications like virtual energy consumption simulation experiments, cost estimation, structural calculations and so forth. The envisaged solution would be through mapping product parameters and attributes to a software independent building information model and ensuring that it is valid and up-to-date.

Chapter 3

The Statement of the Problem

3.1 Introduction

The last chapter has introduced the state-of-the-art of the research work done in the area of electronic product catalogues and the transfer of product data across AEC participants. It should be mentioned that the aim of this work is not developing an electronic product library that overcomes the shortcomings of previous research work, it is however, the trial to link continually updated life-cycle product data to software independent building information models all over the life span of the construction product itself.

The chapter addresses some points that the author thinks, might be partially responsible for electronic transfer of construction product data, not becoming a common practice. Among these points is the fact that some research work has tried to search for problems that could be solved by new IT technologies, and in many cases the problems were tailored to fit to the IT solution and its capabilities. This can be described as *"putting the carriage in front of the horse"*. Thus, the author thought it might be a good idea to spend sometime not only on studying the capabilities of new technologies but also on studying the problem through a practical commercial value chain analysis for the construction industry. This analysis, in addition to the shortcomings of the previous research work may be able to put forward some guidelines for this work and for any further work by other researchers .

3.2 The Value and Supply Chains

3.2.1 Information Middlemen

A debate has taken place in the past few years about the role of information middlemen in the

Internet era, whether this role will demolish or restructure itself in another form that adapts itself with the new market needs. The Internet has opened new windows of opportunities for a totally new infrastructure to form networks and use them for transferring digital information between people, firms and software. The aggregation of three aspects: digital Information, an available network infrastructure and customer value, has led to the appearance of new business patterns, models and strategies. (Finne et al 2003) Information middlemen act as intermediaries between those who have information and those who need it. They also add value to the product by producing information themselves. The value[3] and supply[4] chains in the construction industry are becoming more and more dependant on Information brokers, as portal websites are increasing customers' value by increasing their information content and improving their search mechanisms i.e. *a competitive advantage.*

Porter's value chain (Porter, 1998) and Coase's (Coase, 1988) TCT (Transaction Cost Theory) provide a good explanation to the above mentioned trend. They emphasis that a general strategy for increasing customer value is differentiation. *" The buyer's value chain is the key to understanding the underlying basis of differentiation – creating value for the buyer through lowering the buyer's cost or improving buyers performance. Differentiation results from both actual uniqueness in creating buyer value and from the ability to signal that value so that buyers perceive it."* (Porter, 1998)

Sarkar et al (1995) use Coase's TCT from 1937 to emphasis that electronic commerce will not lead to the disappearance of middlemen. Figure 3.1 shows that an organization is in need for middlemen when T2 + T3 < T1. If T1 < T2 + T3, then the consumer deals with the producer directly. (Coase 1988) makes it clear that transaction costs are not only the

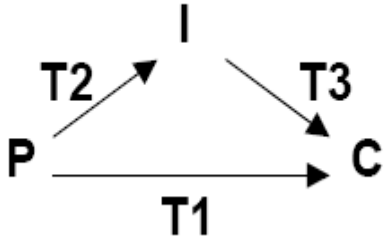


Figure 3.1 T:Transaction between I: Intermediaries, P:Producer and C: Customer, ,(Sarker et al 1995)

3 *"A **Value Chain** is a collection of business entities, each of which contributes to a product or a service that makes up a finished good (or service) purchased and used by an end-user customer."* Gistics Glossary, http://www.gistics.com

4 *"A **supply chain** is a network of facilities and distribution options that performs the functions of procurement of materials; transformation of these material into intermediate and finished products; and distribution of these finished products to customers."* (Source: Ganeshan et al 1995).

the direct cost or price, but also includes everything needed to carry out a market transaction. This could include things such as search for information costs, bargaining and decision costs.

Researchers like (Finne 2003) argue that the ability of portal websites and construction product middlemen to restructure information in formats that their customers' computer applications can understand, would reduce transaction costs and act as a value added competitive advantage. Furthermore, if the services provided by middlemen could include the provision of product information covering the life-span of the construction product, this would lead to significant *economies of scale* (ibid). This is specially true in cases where the middlemen or portal websites are capable of giving customers value, that is greater than the customer's costs for producing the same services themselves. In other words, if the overall costs would still be less than when not using the service. (Porter 1998)

3.2.2 Branding

Branding is one of the marketing strategies used to promote a product. People are reluctant to buy products that do not have a good reputation or did not stand the test of time. Researchers like (Wimmer et al 2000, Smith 2001, Coltman et al 2001) emphasise that a brand name has a significant role on the Internet. Branding is like a stamp of quality assurance. Branding also means the differentiation of the product. Differentiation creates difficulty in comparing products, and can facilitate premium pricing. (Coltman et al 2001, Öörni and Klein 2003 Smith and Brynjolfsson 2001) The quality correlated to a brand name should be also correlated to the amount, dispersion, and trustworthiness of information provided by the service or the product. This is another area where information middlemen could achieve *"delivery on the brand"*. (Willcocks and Plant, 2001)

It seems that the above points have not been widely implemented by current commercial and academic research work. Thus, we could conclude that the above mentioned aspects are of significant importance and should be taken into consideration when attempting to consider

marketing and management aspects that could pull academic work from drawers and push it into practical implementation.

3.2.3 Manufacturers and Suppliers

Suppliers more often than not give brand names to products that are produced by multiple manufacturers so long as these products conform to certain norms and standards. The brand name acts as a symbol of quality, where customers correlate a certain level of quality to the brand name. This association between customer's perception to a product and a certain brand name, plays an important role in marketing strategies. Suppliers often order products to be manufactured for themselves under a certain commercial brand name by a manufacturer. The same manufacturer can be producing the same product under other brand names for other suppliers. Hence, it is important to understand the manufacturer-supplier relation in such cases, where information about construction products can be differentiated in to two types of information, first is the technical information that is best known by the manufacturer and second is the commercial information that is managed by the supplier. An example can be a cement factory that produces cement under multiple names for multiple suppliers, each supplier can sell its cement according to the perception of the customer to the quality of the brand name and the services associated with it.

Thus, it might be one of the shortcomings of the previous research projects, that they did not try to model the separation between manufacturers and suppliers in the supply chain and mostly depended on a single focal point of information which is the supplier or the manufacturer as a single entity, where, however, this segment is fragmented and the information transfer has to depend on a distributed infrastructure that simulates reality rather than the assumption of an ideal case of a single focal point of information. However, there exist also cases where the manufacturer conducts his own marketing strategies and sells his products under his own brand name and pricing strategies. In such cases, the manufacturer and the supplier can be treated as one entity, in cases where the manufacturer plays the supplier's role.

3.2.4 Prefabrication versus on Site Production

One of the peculiarities of the construction industry is that a considerable portion of the construction work is produced on site and not 100% of the products come to the construction site on a back of a lorry. By considering this fact at various stages of the value chain, information that belongs to the products that are fully or partially constructed on site has to be mirrored in the building information model. If we focused on such on site activities, we will find that more often than not they are produced by sub-contractors. At this point the manufacturer–supplier information output in the value chain has to be adjusted to suit the nature of the construction industry. One suggestion to solve this problem would be to consider the main contractor as the supplier and the sub-contractor as the manufacturer. By looking at this suggestion, we find that it is true to a great extent. The sub-contractor is the one who owns the technical information and the main contractor supplies the product or the service in the same manner as the supplier does for prefabricated products. Moreover, the main contractor is more concerned about delivery times, mark-up and organizational business aspects rather than technicalities of the subcontracted work.

3.3 Life Cycle Information and Updates

Most of the mentioned research work has claimed to offer life-cycle information of the construction product. However, the real need is not only for life-cycle information, but for information over the life-cycle of the product. In other words, if the life-cycle information is offered at the design or decision making stage and then it disappears, this is not of a great value to the building information model. There is a need to a permanent source of information about the product that can be easily identified and accessed at all life-cycle stages by all involved AEC disciplines, i.e. i*nformation over the life-cycle rather than life-cycle information at a single point in time*. This approach also controls the acquisition of data and its management. It is better to acquire information about a certain product as it is needed rather than keeping all the needed and unneeded information about each product from the time the decision is taken to include the

product in the project. Furthermore, there are types of dynamic information that need to be monitored and continually updated, e.g. price, availability and so forth.

3.4 Search Mechanisms

The search mechanisms that were addressed in the mentioned research projects can be differentiated into three types:

- Text based searches
- Classifications and Standards searches
- Parametric Searches

3.4.1 Text based searches

The text (Key-Word) based searches suit HTML and PDF files. The key word can be the name of the product, its manufacturer, its brand name or any of its attributes. This type of search is the most dominant one at the majority of suppliers' commercial web pages and portal websites at the time of writing this work.

3.4.2 Searches based on Classifications and Standards

In the search according to classifications and standards, categories of products are displayed and the user has to navigate through them and make a decision. However, the problem with this type of search is its dependence on local classification systems and standards. The same problem was also propagated to some research projects that tried to develop their own XML schemas according to such local classification systems and standards. In the mean time, classification systems and standards are considered as part of the parameters of the product. Hence, its existence is important and allowing multiple classifications and standards to be considered as attributes of a product is also of no less importance. Away from this discussion, it should be also

mentioned that there are researchers who adopt another view; that standards should be avoided, even fought against, because they prevent differentiation and lock-in, and thus premium pricing. (Sharpio and Varian 1999a, Sharpio and Varian, 1999b) At any rate, in the scope of this research work multiple standards and classification systems should be considered as part of the product attributes.

3.4.3 Parametric Searches

The parametric search is the most advanced one of the three types. However, it is not widely implemented. One of the reasons for this problem could be attributed to the lack of standards and norms that manage the taxonomy and identification of the parameters. Normally, the parameters should be extracted from the building information model, then queries are carried out according to these parameters and the chosen product's attributes are instantiated in the model. Hence, it is a machine to machine language with the exception of the final decision-making process for the selection and comparison between candidate construction products.

3.4.4 Retrieving Information using GUIDs

None of the research projects or commercial websites has mentioned the idea of referring to construction product data through a Global Unique IDentifier. It would ultimately not be used as a search mechanism, but it might help retrieving construction product data during the life-cycle of the product. In other words, it might be able to act as the link that ties products in a building information model with its life-cycle information. This might also help products referencing one another, in cases where a composition or aggregation relationship between products exists. Furthermore, it might help aggregating fragmented information that resides in distributed net applications, e.g. technical information from a manufacturer and commercial (business) information from a supplier and so forth.

3.5 A Building Information Model

The ideal case for a building information model is the case where one single data model is used and all parties store and retrieve their data from it, from early design stages till use, maintenance and demolition. (Björk 2003, Eastman 1999) However, this is not the case in reality. The construction industry is fragmented, involves multidisciplinary professions and above all includes a diversity of interests. Hence, this ideal imagination is far away from reality or any practical application. Researchers like (Finne 2003) have the view that the real challenge is to develop extensive and ubiquitous web based services that cover the whole range of players in the CFM (Construction and Facilities Management) process. Moreover, the majority of industry experts see the development towards non-proprietary value adding standardisation initiatives like the IAI[5]/IFC[6] as the major trend. (ITCON 2003, Koivu 2002) Other researchers like (Romo 2002a, Romo 2002b) claim that the existing building information models other than IFC are not complete and that they may co-exist with IFC for sometime before vanishing. Researchers like (Finne 2003) argue that IFC is getting increasingly important and that the use of IFC is just on the brink of taking place. On the other hand (Koivu 2002) adopts a view that IFC might last ten to twenty years before it is developed to a level that can enable full electronic commerce.

(Behrman, 2002) strongly criticizes the difficulty, slow speed of the development and complexity of the implementation of the IFC model. In the meantime, Behrman's standardisation development that is based on each use-case has not been more successful in the AEC industry or replaced the IFC since the publication of the Behrman's report. On the contrary, the IAI has published two versions of the IFC specification and has become the de-facto standard since 2002.

5 International Alliance for Interoperability, http://www.iai-na.org/about/mission.php
6 Industy Foundation Classes, http://www.fiatech.org/projects/idim/ifcs.htm

3.6 Conclusion and Guidelines for the Research Work

3.6.1 Conclusion

This chapter has discussed some issues that are related to the problem of transfer of construction product data between distributed network applications. Among these issues is the value and supply chains.

The chapter came to a conclusion that information middlemen still play an important role in the Internet era and their role will be reinforced with the increase of value added to the customer and as long as Coase's Transaction Cost Theory is valid. The chapter followed this issue by a discussion about the importance of branding in marketing strategies and how it leads often to having the same product under multiple commercial brand names. However, differentiation of the product could still be achieved through the services that are associated with it. This more often that not results in the separation between business information related to the supplier and the technical information related to the manufacturer. An important characteristic of the construction industry is that buildings are still partially prefabricated and the rest of the construction elements are constructed on site. This peculiarity in the value chain necessitates the reflection of both types of product data on the building information model with emphasis on the role of both contractors and subcontractors.

The chapter has also discussed the fact that building information models are in need for life-cycle information all over the life cycle of the construction product and not only at the point of decision making, i.e. information over the life cycle rather than life-cycle information at a single point in time. Moreover it highlighted the importance of product information updates especially in the business and commercial domains.

Various search mechanisms like the key word text based search, searches according to classification systems and standards and parametric searches were discussed. The chapter

introduced the idea of a global unique identifier as a means of product data identification. It is not a substitute to any of the search mechanisms, however, the author thinks it might help in keeping product data linked to the building information model throughout its life cycle.

Finally, the issue of a building information model was discussed and it was concluded that the IFC model with its non-proprietary characteristics is a considerable candidate for the prototype implementation. Further reasons for this decision will be discussed in due course, while proceeding in the chapters of this research work.

3.6.2 Guidelines

The author tried to extract some guidelines from the previous literature review and the analysis that followed it. These Guidelines are:

- The need for the role of the Middleman or the portal website.
- The separation between the information that could be retrieved from the supplier and the manufacturer in the supply chain.
- Considering various options of pre-fabrication and fabrication of construction products on site.
- Considering the construction product hierarchy and its references to its constituents and components.
- Availability of product life-cycle information over the life-cycle of the product and allowing both information updates and extending the product's data.
- The ability to perform parametric searches and to allow for multiple classification systems and standards.

- Identification of product data by using GUIDs.

- Using a non-proprietary Building Information Model

- Independence from commercial software applications and the support of information exchange across heterogeneous platforms.

Chapter four will try to explain a design of a full specification for a model based on the above mentioned guidelines. This model should be implemented in a comprehensive Software prototype, that simulates all participants in the construction value chain.

It should be based on a distributed network system and not on a single database in order to avoid information ownership and management problems.

Furthermore, chapter five will provide a proof of the solution concept developed in chapter four. All parties involved in the construction value chain are simulated in a comprehensive network application according to the above mentioned guidelines and the developed solution concept.

Chapter 4

Model of Proposed Solution

4.1 Introduction

Both the state of the art of BIMs (Building information Models) and electronic product catalogues as well as the shortcomings of the previous research work were discussed in chapters two and three. The author managed to reach a list of guidelines, that might be able to help overcome the identified problems. A major guideline that has been emphasised throughout the discussions in the previous chapters is the establishment of a link between objects in the building information model (IFC model) and their continually updated life-cycle product data - technical and commercial attributes- at the manufacturer and supplier respectively. This is hoped to enable multidisciplinary cross industrial life-cycle information to be captured by IFC compatible applications.

This chapter explains a new approach that is envisaged to help automating the development of a building information model. The author suggests that the product information model should be produced as a part of the construction product itself. This information model grows with the development of the product e.g. the manufacturer would be responsible for the technical properties and later the supplier or the wholesaler would be responsible for the dynamic commercial aspects, when it is on sale at the physical market place or the virtual market space (the Internet). The aggregation of this type of multidisciplinary and cross industrial information is represented and made available on-line through the "OIPs" (**O**bject **I**nformation **P**acks).

4.2 OIP Specifications

OIPs stand for Object Information Packs. An OIP is defined by the author as *"A multidisciplinary cross industrial continually updated pack of information about a construction product or a*

service, upon which there is a need to retrieve predefined information at any point in the value chain. This information pack acts as a base unit of information supply to BIMs (Building Information Models) throughout the building's overall life cycle."

In other words, an OIP is a construction oriented global life cycle identifier that links cross industrial multidisciplinary information about a construction product or a service. It has been designed to fit in an information exchange environment that suits the characteristics of the various procurement systems in the construction industry's value chain .

4.2.1 Producer

The OIP has to represent both the technical and commercial information of a construction product or service. The information is usually produced jointly between the manufacturer from one side and the supplier, retailer, importer or wholesaler from the other side. This means that the OIP is finally determined at the point of aggregation of both types of information i.e. technical and commercial. This aggregation or double composition ensures the uniqueness of the OIP as an identifier of the construction product or service and enables the retrieval of its dynamic properties, i.e. commercial properties can be continually updated and the technical properties can be extended. The complete OIP identifier is issued by the organization that owns the brand name of the product regardless where, and by whom it has been manufactured.

On the other hand, in the case of construction products that are totally or partially manufactured on site, the main contractor is considered to be the supplier, whereas the subcontractor (specialist) would be considered as the manufacturer and consequently is responsible for the technical information of the product. There are also cases where the manufacturer himself is the brand name holder. In such cases, the manufacturer would be responsible for both kinds of information.

4.2.2 Format and Design of OIP

The OIP is represented as a global unique identifier that enables the retrieval of structured data, by agreed message standards from one party (computer) to another, by electronic means with minimum human intervention, i.e. machine-to-machine language.

Figure 4.1 shows that the OIP identifier consists of two main parts; the technical identifier that consists of nine alphanumeric digits and the commercial part that consists of four alphanumeric digits. Both of them compose the OIP identification and formulate it as a global unique identifier for referencing a construction product or a service. A product under different brand names can have one or more OIPs with the same common technical identifier, but with various commercial identifiers. This enables the OIP to represent commercial properties supplied by the brand name holder in addition to the technical properties provided by the manufacturer. The OIP technical information is relatively static as the technical properties do not change but can be extended. On the contrary, the commercial aspects like price, availability and discounts can change dynamically.

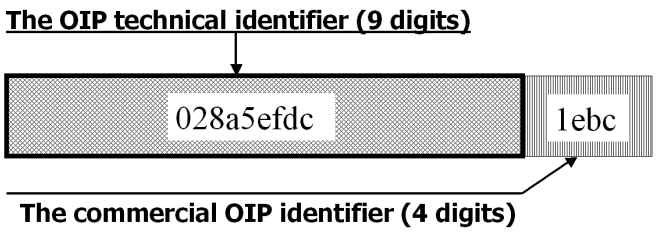


Figure 4.1 The Structure of the OIP Identifier

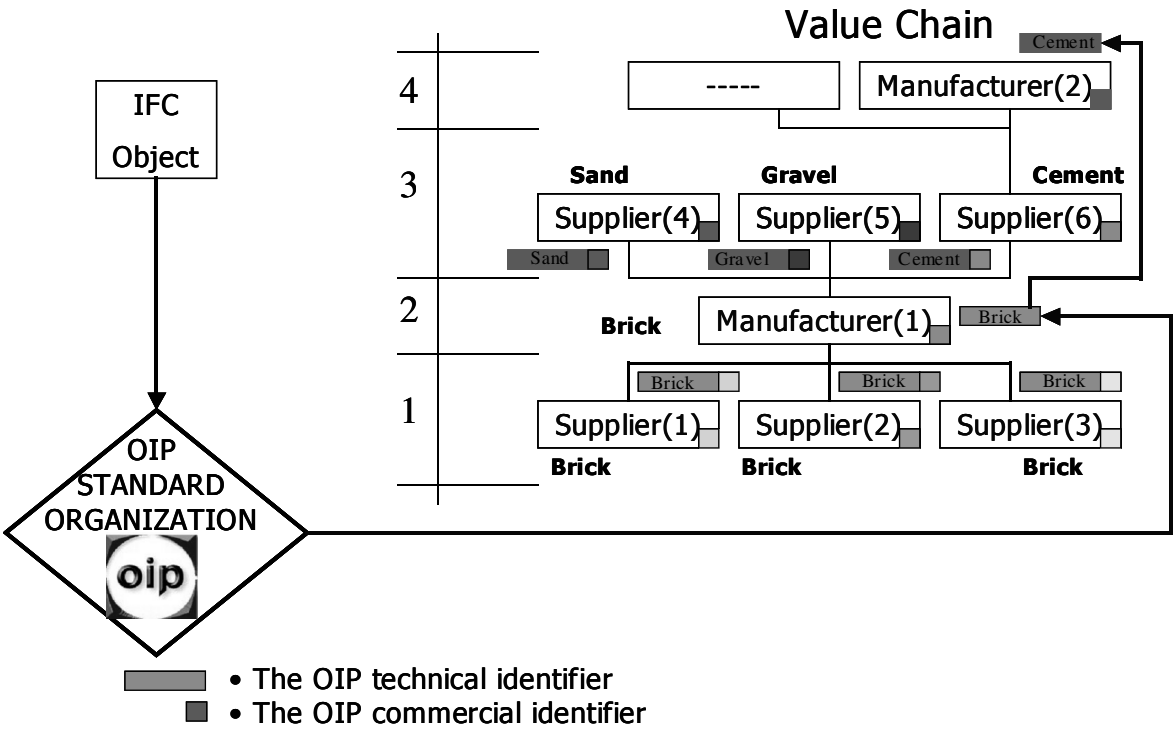


Figure 4.2 The OIP formulation of the OIP and constituents referencing

Figure 4.2 represents an abstracted example that shows how an OIP identifier is formulated and how it can reference the technical information packs of its constituents. Furthermore, it shows the entire relation between the IFC model objects, suppliers, manufacturers and the OIP organization. It is an example of a simple brick that is sold by an arbitrary number of suppliers (at level 1). Each supplier has his own commercial properties that are related to each specific product. The brick consists of cement, sand and gravel. The brick itself has technical properties provided by its manufacturer (at level 2). The brick references the technical information of the cement that is made by a manufacturer at level 4 through its OIP technical identifier.

As a general rule, the OIP identifier is only complete, when its both components (the technical and commercial parts) are present. The manufacturers or the suppliers have to register the technical properties according to the IFC model and its published property sets at the OIP Standard Organization.

4.2.3 Degree of Granularity

One of the problems facing OIPs is the degree of nesting of elements. In other words, to what extent would the OIP reference other OIPs (technical data) of the constituent components. In some cases like in electromechanical equipment, we can not determine at which level should the OIP referencing stop. Is it to the screw level, or to the material of the screw… . To put an end to this problem, OIP is designed to reference other constituents (construction products or materials) for two levels, as a maximum detailing level e.g. a wall may reference a concrete brick as a material and in turn the brick may reference cement, sand and gravel as leaf elements. Meanwhile, there is an ISO Standard (ISO 13584 Plib), which is a STEP-EXPRESS based standard that is designed specially for this purpose. Moreover, it is technically feasible to be referenced from OIPs whenever needed.

4.2.4 An OIP Organization

An important task contributing to the success of OIPs is the responsibility of the management of the OIPs themselves. Things such as the allocation of identifiers and keeping records of technical properties of products – in the form of structured data - have to be managed by an international non-aligned organization. Therefore, the main mission statement of the OIP organisation is the allocation of the OIP technical identifiers and keeping records of technical information about products in an on-line database, where it can be accessed at any time by any user by electronic means.

4.2.4.1 OIP Layering System

As it can be seen from figure 4.3, the OIP data structure hierarchy consists of three top-down layers, i.e. The upper layers can reference the lower layers and not vice versa. For example, a product in the domain layer can reference a material in the resources layer – elements in the resources layer are common for all elements in the product and domain layers - and the opposite is not possible.

In the scope of this work, only the product entity in the domains layer, the on-site and pre-fabricated products in the products layer and properties and materials in the resources level are addressed.

It should be also mentioned that the Kernel of the model which resides at the products layer contains all the relations that link the upper layers with the resources layer. The relations act as the cross-reference tables in a relational data model and as objectified relationship classes in an object oriented data model, as it is explained in detail in the model implementation in chapter five.

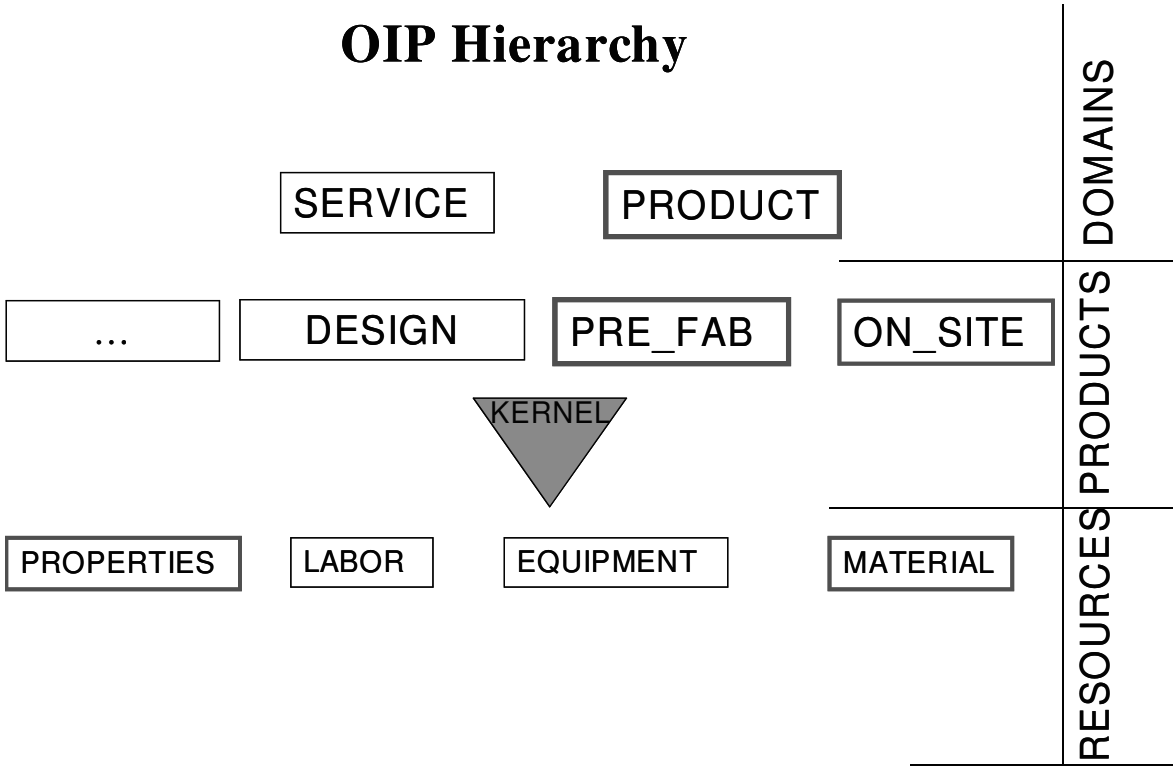


Figure 4.3 The layering System of the OIP data structure

The OIP model has been designed in such a manner to enable its future extensibility. It can be noticed from figure 4.3 that there are possibilities for horizontal extensions of the model at its different layers.

Figure 4.4 shows an abstracted example of the OIP data structure, for simplicity reasons, it does not include the relations of the Kernel. As it can be seen from the figure, the OIP identifier can

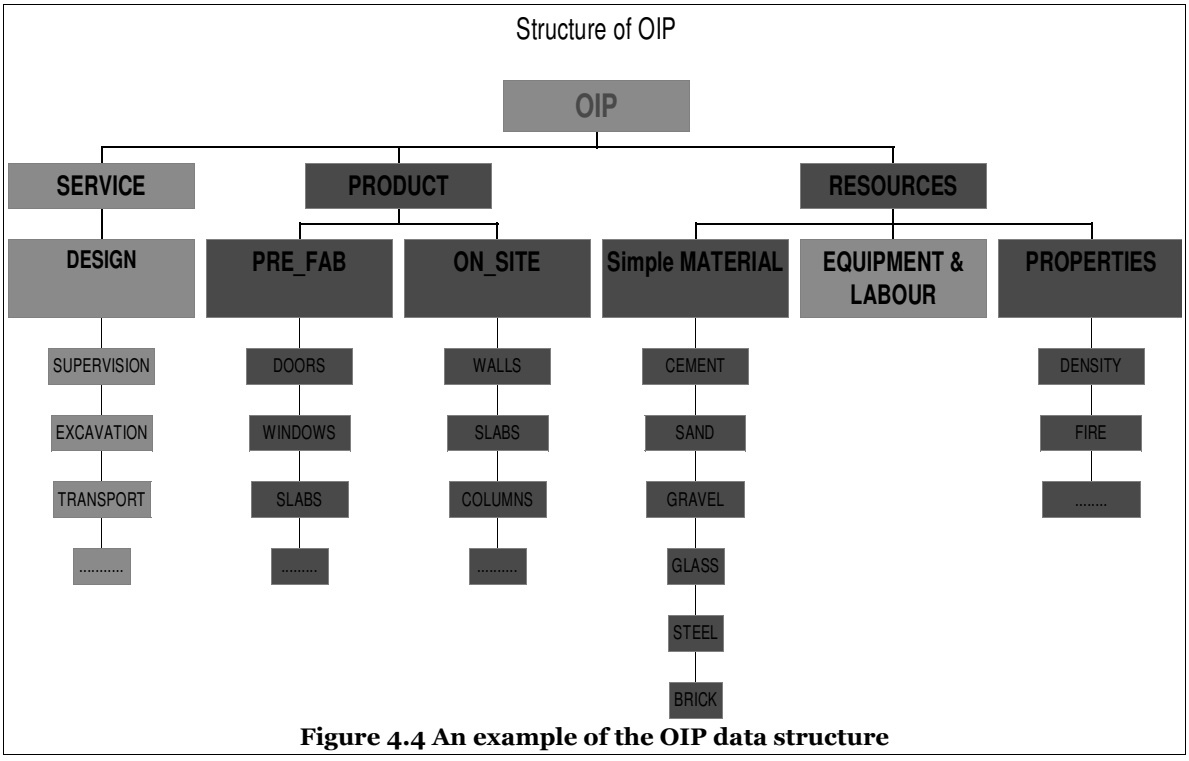


Figure 4.4 An example of the OIP data structure

represent a service, a product or a resource. The service can be a design, supervision, excavation, transport and so forth. They are all considered to be activities or processes that are performed during a construction project to change its state from one state to another.

The product can be prefabricated, constructed on site or a mixture of both at the same time. Figure 4.4 also shows examples for both on-site fabricated elements as well as prefabricated elements.

The resources are considered to be consumed materials, working force (labour), equipment, or properties that are used for product definition and specification at the higher layers of the OIP hierarchy.

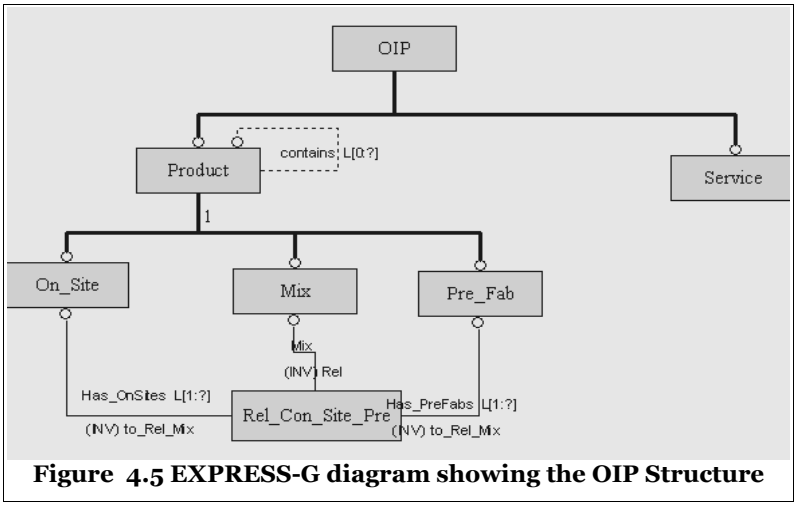


Figure 4.5 EXPRESS-G diagram showing the OIP Structure

Figures 4.5 and 4.6 represent EXPRESS-G diagrams that describe the OIP information structure. An OIP element in the current version is a product. In future extensions, it should also be able to include the services domain. A product may reference a list of zero to infinity of its constituents (other products), as shown by the optional attribute of the product entity . The product itself may be constructed on-site, prefabricated or a mixture of both. In the last case the relation (Rel_Con_Site_Pre) is used to map the On_Site as well as the prefabricated constituents of the product together as shown by the inverse relations in figure 4.5.

The resources can be labour, materials, equipment, or properties. In the current version of OIPs only the materials and properties are supported. A material can also reference its constituent materials (if they exist, as shown by the optional *"Material_Reference"* attribute). The properties are defined as a set of IFC properties, together with the definition of units of measurements according to the SI[7] Units system.

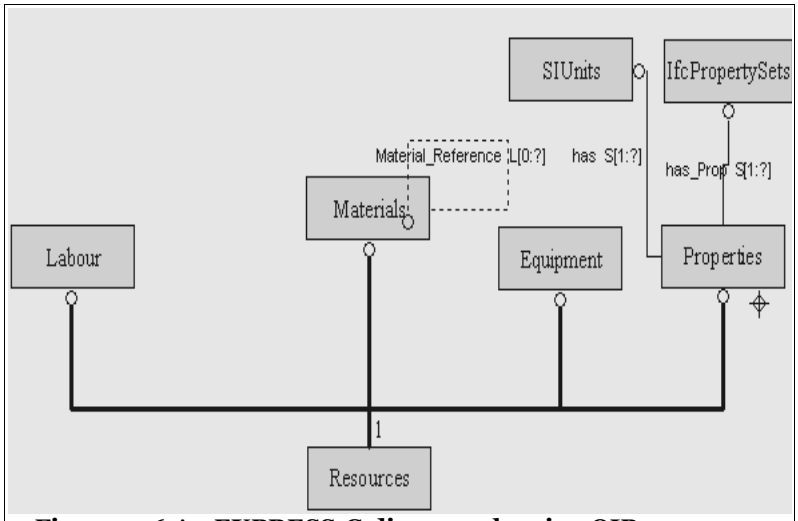


Figure 4.6 An EXPRESS-G diagram showing OIP resources

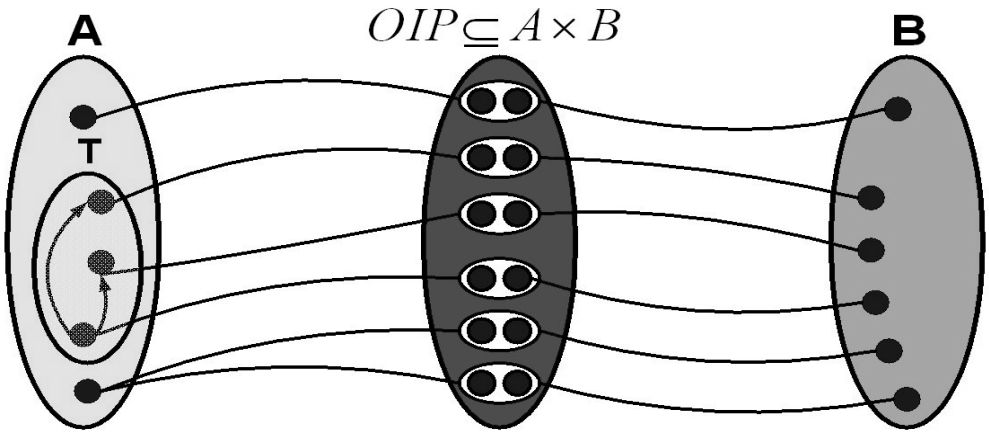
4.2.5 OIP Implementation

This section describes the implementation of the OIP concept in real life scenarios, together with a simple example using a limited number of product attributes to enable the reader to follow the logic behind the OIP's idea. Before the example is presented, the basic concept of the OIP is clarified.

7 The International System of Units from NIST, http://physics.nist.gov/cuu/Units

4.2.5.1 The Basic Concept

As it can be seen from figure 4.7, the set A represents the technical OIP identifiers and set B represents the commercial OIP identifiers. The two parts are combined together to form the complete OIP identifier. It can also be seen that a technical OIP can reference the technical OIPs of its constituents to form the sub-set T (Nour 2003). In the meantime, one technical OIP can be combined with more than one commercial OIP. This represents the case where the same product is sold under two or more brand-names.



$A := \{a | a \text{ is an OIP technical ID}\}$

$B := \{b | b \text{ is an OIP commercial ID}\}$

$OIP := \{(a, b) \in A \times B | a \text{ is an OIP technical ID}, b \text{ is an OIP commercial ID}\} \subseteq A \times B$

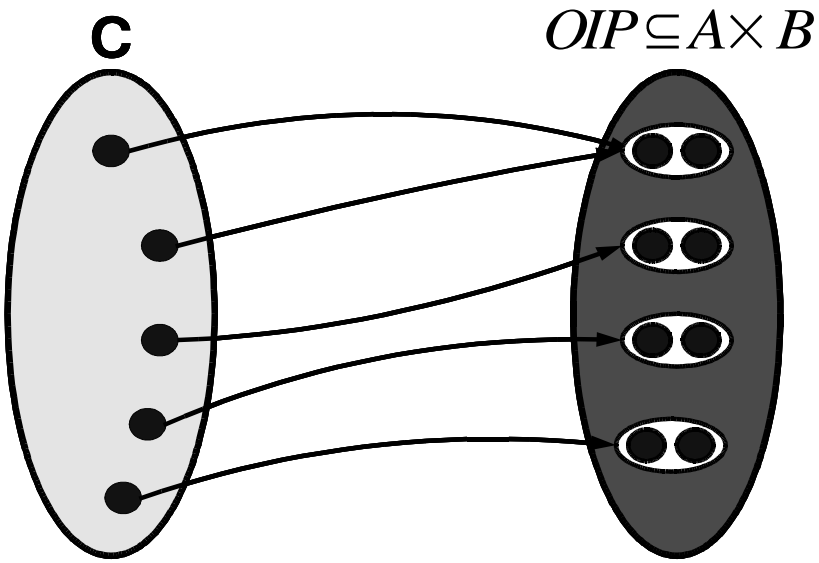
$T \subseteq A \times A \qquad T := \{(a, b) \in A \times A | b \text{ references } a\}$

Figure 4.7 The mathematical relations between the OIP identifiers

Figure 4.8 shows the mapping relation between objects in the IFC model (instances of the entity IfcProduct), represented as the set C and the OIPs. The mapping relation X represents the mapping between the three sets A, B and C

The whole idea can be simplified as a mapping and merging from two source models (S1 and S2) to a target model (T1). In figure 4.9, S1 represents the OIP organization, where all multidisciplinary technical information resides. S2 represents the supplier or brand name holder

of the product; where all the commercial properties reside. T1 represents the client or the user, where it is envisaged to be a group of AEC applications built on top of the IFC model. Finally, a software application should be situated between the source models and the target model to carry out the data mapping and merging processes.



$$X : C \rightarrow (OIP)$$
$$with\ C := \{c \mid c\ is\ an\ instance\ of\ IfcProduct \in the\ IFC\ model\}$$
$$X := \{(c(a,b)) \in C \times (A \times B) \mid c\ is\ an instance\ of\ IfcProduct \in IFC\ model, (a,b) \in OIP\}$$

Figure 4.8 The mapping between objects in the IFC model and OIPs

The user(s) (client(s)) - who is supposed to be using applications that are built on the top of the IFC model - conducts queries according to the search parameters that are extracted from his building information model. The result of a query should be a set of candidate elements, where the user is able to select from and instantiate the OIP of the selected element in the building information model.

Later, whenever a need for any piece of information arises by any AEC discipline, during the whole life-cycle of the building project, it should be able to be retrieved through the OIP identifier (tag).

The latter has the advantage of keeping the IFC model free from any unneeded information. Moreover, the ability to retrieve information during the life-cycle of the building remains available through the OIP.

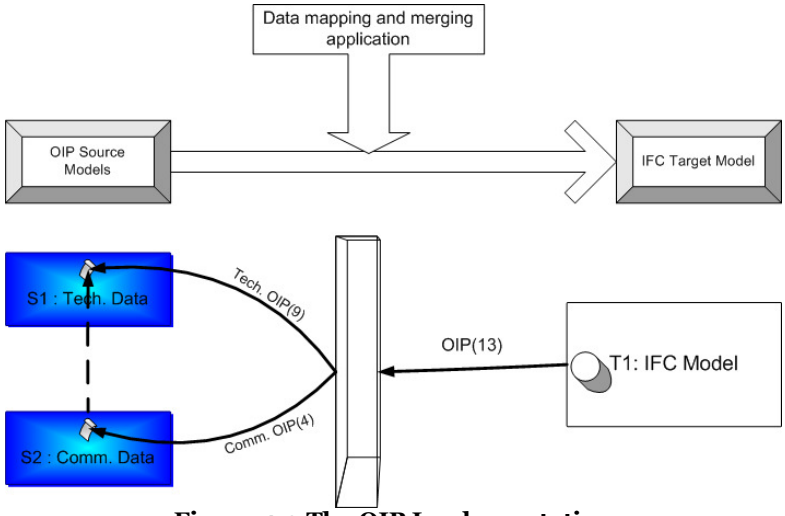


Figure 4.9 The OIP Implementation

It should be mentioned that the technical information is registered by the manufacturer at the OIP organisation. This pack of technical information can also reference the technical information of its constituents, if they exist. For example, a door can reference its hinges or lock and the lock can reference its keys and so forth.

The commercial properties of elements also have references to the technical information. In a typical scenario, the query is submitted to the supplier, brand name holder or portal website that has references to an arbitrary number of suppliers. Different mechanisms for conducting the queries over the world wide web together with the database queries are discussed in detail at the implementation section of this work in chapter five.

4.2.5.2 Scenarios

There are many different scenarios where the OIP concept could be implemented. However, this section focuses on two main scenarios, where there is a requirements or specifications model that has to be developed to a design model with real construction products. First is the traditional way of using paper based catalogues or CD-ROMs. The OIP reference (identifier) can be instantiated by the CAD package or by adhoc software. Life-cycle information can then be retrieved using the OIP identifier and the required data can be mapped and merged to the IFC model at the client's side (through a distributed network application).(Nour et al 2003)

The second scenario is a more complex one. It depends on the capture of the required object parameters from the CAD/IFC model. These parameters are used to carry out a parametric search (attribute based) versus a descriptive search in the first scenario. This can be achieved by using SQL, XML (Tolaman et al), EXPRESS-X or any software independent means. The result of this search is a list of products that satisfy the search parameters. This list can be sorted according to the value of any selection attribute, e.g. price, sound absorption coefficient, fire resistance and so forth.

A step forward in this approach would be the selection and appraisal process i.e. decision making versus taking. This can be done by conducting a virtual experiment under simulated real conditions, where the product will be performing (i.e. providing full context conditions), as mentioned earlier in chapter two. The experiment is repeated several times on the short listed products. Each time a product from the candidate products is substituted, tested and ranked according to the performance in the virtual experiment.

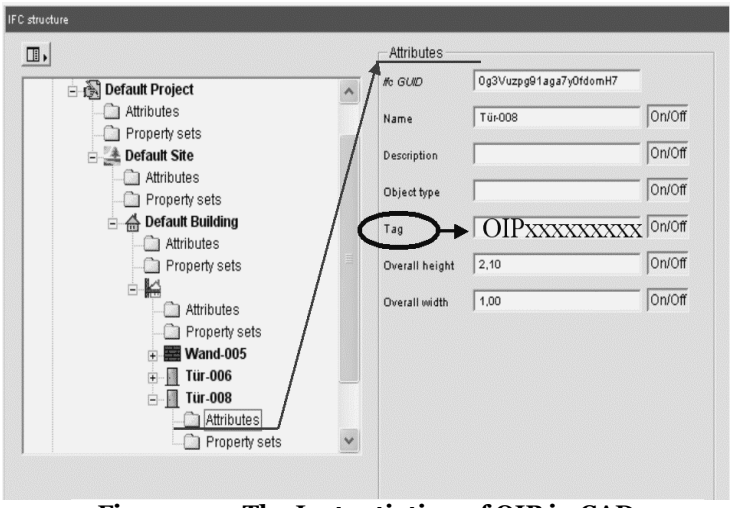


Figure 4.10 The Instantiation of OIP in CAD

By using this approach the user can determine a set of weighted performance indicators that represent the full context in which the product would be used. This coincides to a great extend with the principals of TQM (Total Quality Management); which is quality of performance rather than specifications (Nelson 1996). Any need for extra or up to date information should be reached through the OIP unique identifier. Nevertheless, this process is out of the scope of this work.

4.2.5.3 Example

By looking at a simple example of a door (IfcDoor), a door is selected according to the first scenario from an electronic catalogue from a portal web site (figure 4.12). It is transferred through a drag and drop environment to the CAD application, where the OIP is instantiated to the door's Tag in the IFC attributes (figure 4.10). The door in the IFC model consists of two main parts: the Lining and the panel as shown in figure 4.11. The IFC published property sets of the door include things like the operation direction, overall size, operation properties (swing), material, panel and lining detailed properties, door common properties like: Infiltration, Thermal Transmittance, Fire, Security and Acoustic Ratings and so forth. These properties might be needed in later design or facility management stages by different AEC disciplines.

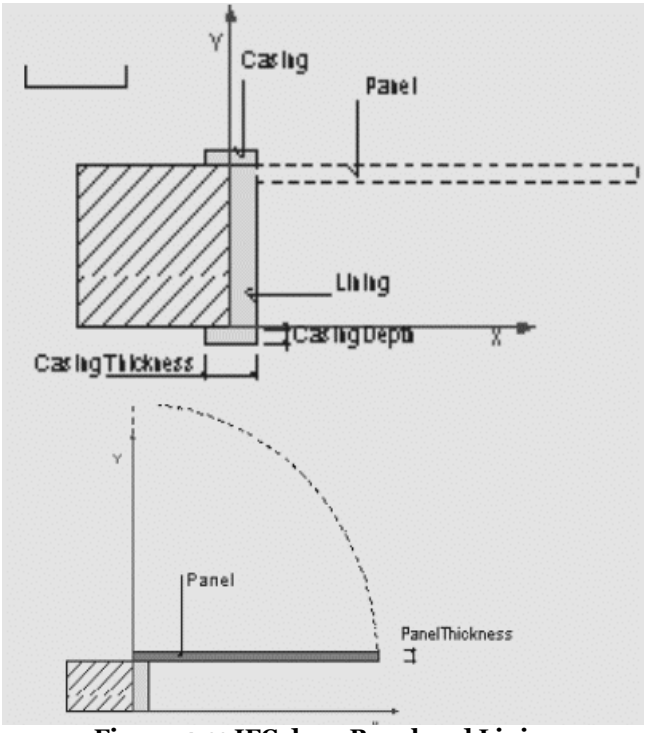


Figure 4.11 IFC door Panel and Lining

Access to this information should be enabled through the OIP. If at any time the need for more information by any discipline arises, the product OIP can be accessed and the property can be selected and merged to the IFC model at the client's side. If the product needs to be changed for any reason, the same parameters could be used to conduct a new parametric search. This can also be done as a result of a commercial property change e.g. price or availability updates. If the product needs to be substituted with another product instance then a new OIP unique identifier substitutes the old one and so forth.

4.2.6 Limitations

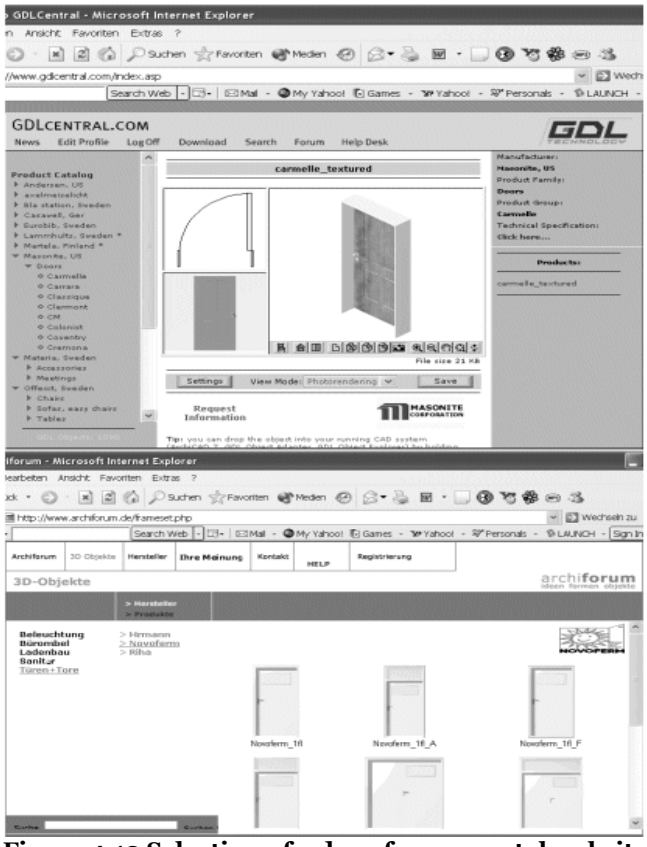


Figure 4.12 Selection of a door from a portal website

OIPs are neither aimed by any means to solve the taxonomy problems of the construction products' properties nor expected to develop a new ontology. Thus, the product properties are limited to the attributes and published property sets of the IFC2x model (ISO PAS 16793 (IAIntern 2003)). This enables the exchange of multidisciplinary cross industrial technical properties between parties beyond national borders without any miss-understandings due to differences in languages, classification systems or organisational cultures. However, the commercial properties will remain subject to international trading conventions and standards. Nevertheless, property names of some technical properties - that are not yet defined in the IFC2x model - could still be used side by side with the IFC2x published property sets, with the hope that the IAI will include them to its publishing list in future.

Furthermore, the IAI does not provide published property sets at the construction materials level. Thus, until this issue is achieved by the IAI in future, it is allowed to use other international conventions. The latter is quite normal, when considering the evolution of new systems and the change from one system to another. There has to be an overlapping transition period, where the old and new systems exist side by side to each other. It resembles introducing the Euro as a common currency to the European Union. There can not be a sudden change of systems in a single point in time. Furthermore, the feedback from the new system's application is always crucial to its success.

4.3 Conclusion

This chapter has introduced the OIP approach that might be able to help overcoming the problems that were identified in the previous chapters. It could be concluded that the OIP is not only an identifier that facilitates the retrieval of predefined information about construction products or services according to the IFC2x model and its published property sets, but also an information data structure that has a three layers top down hierarchy (domain, product and resource layers). This hierarchy is reflected in the design of the database structure according to the relations defined in the kernel of the system at the products layer. This structure is applied in a runtime object oriented model and a persistent relational model (Microsoft Access Database) in chapter five, where a mapping between the two models is provided.

The OIP concept depends on a distributed information network that emphasises the segregation of technical and commercial product information in the value chain. In the meantime, both information fragments are combined together at a certain point in the value chain to facilitate the retrieval of any needed information by any discipline during the whole product's life-cycle.

The OIP approach alone is not enough to overcome the communication and interoperability problems. The solution at the client side, which is represented by the development of software tools that enable the mapping and merging of data about construction products according to the IFC model is of paramount importance.

Moreover, the software tools at the client side go beyond the mapping and merging of product data to the IFC model to performing a whole range of instantiation, deletion, update processes, in addition to defining new query parameters in the model as well as extracting query parameters that are defined by other software tools e.g. CAD, in addition to conducting parametric searches.

A simulation of a whole network distributes system is demonstrated in detail in chapter five (the

implementation). Moreover, Manufacturers and suppliers roles are also simulated to provide a realistic proof of concept of this work.

Chapter 5

Prototype Implementation

5.1 Introduction

This chapter tries to provide a proof of concept for the OIP approach that has been discussed in the previous chapter. As it can be seen from the map view in figure 5.1, all the participants, i.e. manufacturers, suppliers, portal websites, the OIP organisation and the client (user) are simulated in a distributed network application using the Java RMI (Remote Method Invocation) and multi-threaded Java Sockets communication technologies, in addition to the Java JDBC for dealing with data residing in relational databases at the OIP organisation and the portal website. Moreover, the Java Swing, Java AWT and Java 2D packages, are used in the graphical user interfaces, visualisation of the IFC model in different ways, and finally for mapping and merging

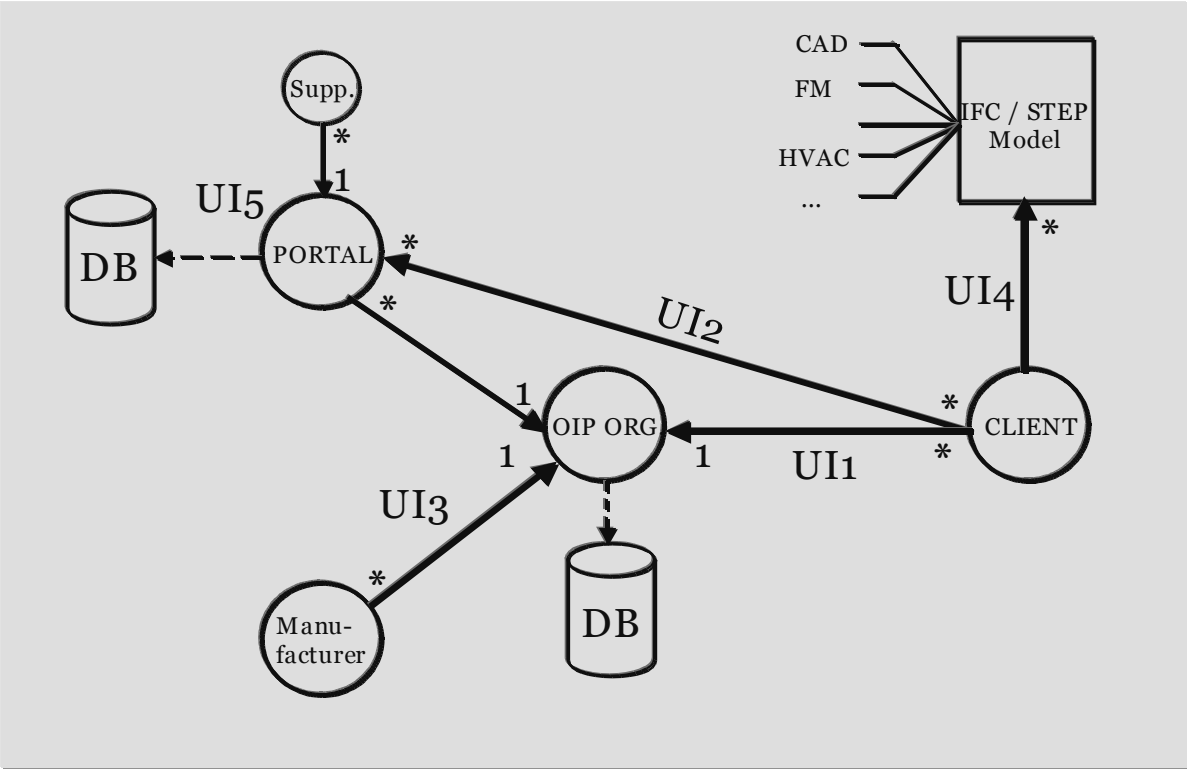


Figure 5.1 A Map View of the OIP System

product data into the IFC model. Moreover, the Java Compiler Compiler technology is used for developing a STEP ISO-10303 parser that is capable of parsing IFC models through the STEP ISO 10303-P21 exchange format.

The technologies are not discussed in the scope of this work, as they are not an aim by themselves, and hence the reader is advised to refer to the official documentations, whenever needed. Readers with a basic background of the above mentioned technologies in addition to the IFC-2x model, the EXPRESS language and its mapping to STEP ISO 10303-P21 should not find difficulties in tracing what is going on. Nevertheless, the author tried to focus on the solution's concepts rather than the technicalities of the solutions. Readers who are interested in the technical solutions can refer to the appendices and the stated references.

Figure 5.1 represents a map view of the developed system. The scenario begins by the manufacturer, who registers the technical information of his product at the OIP organisation's database, where the product is allocated an OIP technical identifier. This is done through a network application that has the (GUI) Graphical User Interface (UI3) in figure 5.1. The GUI is also demonstrated by video in appendix C (demos/UI3/*.avi). Meanwhile, the manufacturer's side is discussed in detail in section 5.2.

The chapter then moves to explaining the internal data structure of the OIP organisation. It consists of a persistent relational model, in addition to an object oriented model. The latter is constructed at runtime as a result of executing queries at the OIP organisation. Hence, a mapping between both models at runtime is discussed in section 5.3.3 together with the supported search mechanisms.

After registering the technical information by the manufacturer at the OIP organisation, the suppliers record themselves at the portal website in relation to products whose technical information has already been registered at the OIP organisation, together with the commercial

properties of the products, using a network application that has the graphical user interface UI5 as shown in figures 5.1, 5.14 and 5.15 and the video demonstrations in appendix C (demos/UI5/*). Each product is allocated a unique commercial identifier, and hence, both parts of the OIP identifier are present at the portal website's database. This is discussed in detail in section 5.4.

The client side is rather complex and includes many software tools that were developed by the author to provide a proof of concept of this work. The main objective of these tools is to transfer the IFC/CAD model obtained from a commercial CAD application to a *requirements model,* as a first stage, then to one or more *design models*[8] at later stages. The user specifies the properties of the construction products in his/her model. The user's explicitly defined specification together with the product's attributes and properties that are extracted from the geometrical CAD model (e.g. the width and height of a door or a window) are considered to be the main constituents of the parametric search which is conducted by the user to find candidate products from electronic product catalogues. The user makes a selection decision and chooses one of the candidate products, and hence, the model starts to change from being (a *requirements model* or a *specifications model*) to being a *design model.*

The software tools developed at the client side include parsing and interpreting STEP ISO 10303-P21 files, visualization of the IFC model in different ways and carrying out different operations on the IFC model.

Once the client has selected a product and instantiated the OIP identifier at the tag of the IFC element, any piece of information that is provided by the supplier or manufacturer could be retrieved throughout its overall life span. Moreover, any information updates can be synchronized on-line with the IFC model at the client's side, as seen in the video demonstration in (appendix C/demos/UI4/Updates).

8 All CAD/IFC, requirement and design models are found in (appendix C/testing_models/Req_to_Des) and are demonstrated by video in (appendix C/demos/UI4)

Finally, some work flow management problems that were encountered by the author and resulted in loss of transferred data by commercial software applications are discussed – in section 5.7 – together with some suggestions to rectify such problems.

The author thought it might be a good idea to give a simple traceable example using real test data (in tables 5.1 and 5.2) that can be followed up throughout the sections of this chapter together with the video demonstrations in (appendix C/demos).

Attribute Name	***Attribute Value***
IfcBuildingElement	IfcDoor
Overall height	2.10 m
Overall width	1.00 m
Material	**STEEL**
Operation	SINGLE_SWING_LEFT
Location	External
Thermal Transmittance Coefficient	0.777 (U-Value) W/m2K
Classification	ISO9000, DIN1234, BS123
Price	1222
Currency	EUR
Country of Origin	GERMANY
Brand Name	BAB
Availability	True

Table 5.1 Example of OIP product Data for a simple steel door

Attribute Name	***Attribute Value***
Material Name	**STEEL**
Density	7800 kg/m3
Classification	ISO9000

Table 5.2 Example of OIP Material Data for steel

5.2 Manufacturer Side

The manufacturer side is added to this work for demonstration reasons and to show how easy is it for the manufacturer to register the technical properties of his product on line at the OIP

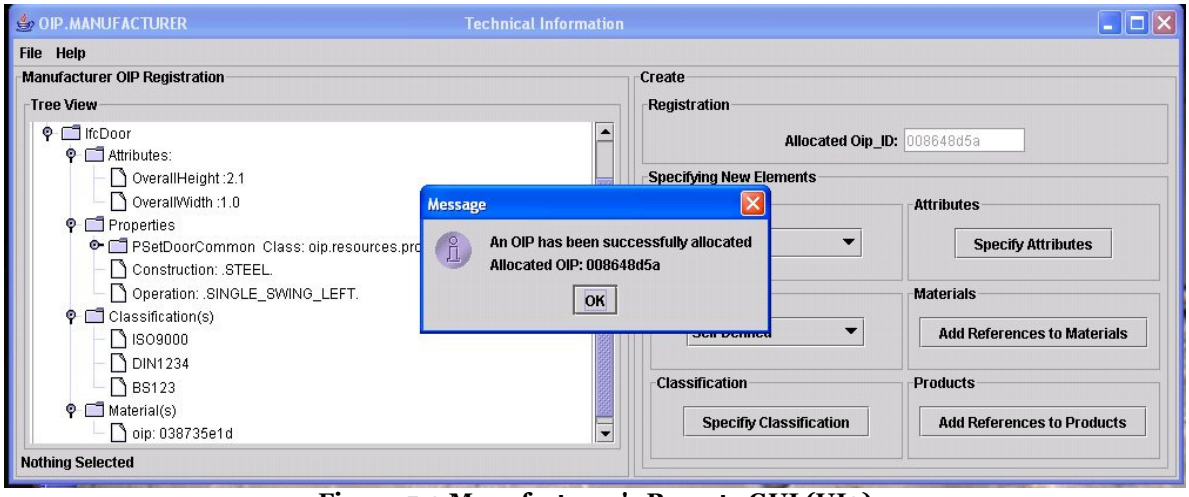


Figure 5.2 Manufacturer's Remote GUI (UI3)

organisation. The graphical user interface (UI3) at the manufacturer's side is shown in figure 5.2 and in the demo in appendix C (demos/UI3[9]). The manufacturer specifies his product's attributes, properties, classifications and constituents of other products or materials. The product's data is represented as a tree on the left hand side of the GUI. This enables the manufacturer to monitor the definition of his product data and to revise it carefully before finally submitting it to the OIP organisation. Once the manufacturer is sure of the information that he wants to register, he submits the information about his product which is revised on-line by the OIP organisation to ensure the correct referencing of constituent products or materials OIP identifiers. In other words, if the technical information of a door is being specified and this door references an OIP of a material e.g. Wood, then the OIP organisation has to check the correctness of the reference. Upon successful registration, an OIP technical identifier is then generated and allocated to the product on-line, as shown in figure 5.2 and appendix C/demos/UI3.

5.3 OIP Organisation

As mentioned earlier in chapter four, the main mission statement of the OIP organisation is

9 The folder contains two video files; "STEEL" and "Door", the material is created first, then the door that has a reference to it. Thus "STEEL.avi" should be watched before "Manufacturer.avi".

keeping records of construction products', materials' properties in a structured manner that facilitates the capture of multidisciplinary cross industrial life-cycle information by IFC compatible applications at the client side, in addition to the management and allocation of global unique identifiers for the elements' technical information. In this stage the technical information about a construction product should have been recorded in the OIP organization by the manufacturer and allocated a global unique identifier for the Object Information Pack, as shown in section 5.2. The coming section reveals the internal data structure of the product data residing in the OIP organization. The data is persistently saved in a relational database and converted at run time as a result of SQL queries to the object oriented model that is described in section 5.3.1. This happens when the OIP organisation receives a query from the client side or portal websites. A query is executed in the relational model and the OIP products (objects) that satisfy the query conditions are built up instantly at run time in the object oriented model, where the properties of the products can be navigated by the client on the remote graphical user interface, as shown in figure 5.12

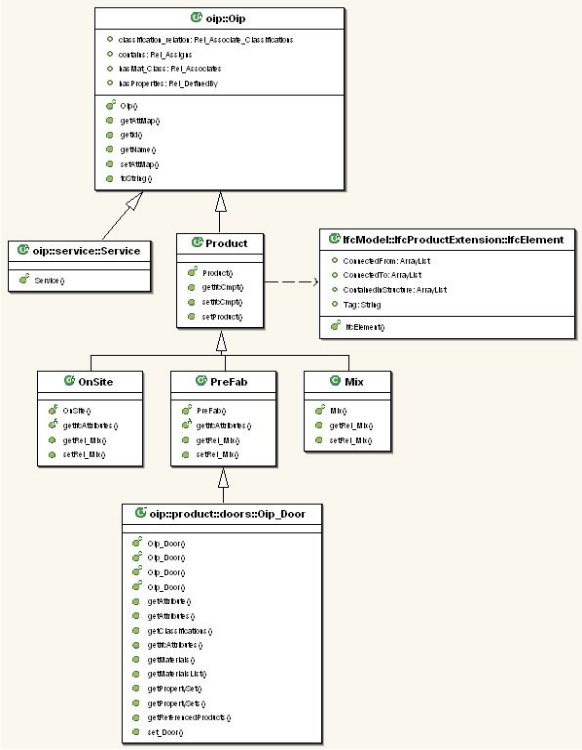


Figure 5.3 The UML diagram of the OIP construction products

5.3.1 The OIP Object Oriented Model

The OIP object oriented model represents exactly the theory behind the OIP concept as discussed earlier in chapter four. The diagrams in chapter four and the UML diagrams in this section show together the structure of the run time OIP object oriented model. By looking at the UML diagram in figure 5.3, we could notice that an OIP is a super type of either a service or a product. An OIP product has a reference to an IFC element. The product itself can be a prefabricated, constructed on-site or a mixture of both. The UML diagram also shows an example of an OIP_Door that

inherits from the "*PreFab*" entity. The reader can refer to the EXPRESS-G diagram in figure 4.7 in chapter four to compare the theoretical design intention and the implementation in this chapter.

On the other hand, figure 5.4 shows the object oriented structure of the OIP kernel. There are four main relations that inherit from the super class Rel_Root (Rel_Assigns, Rel_DefinedBy, Rel_Mix, Rel_Associates). These relations are objectified relationship classes that link elements

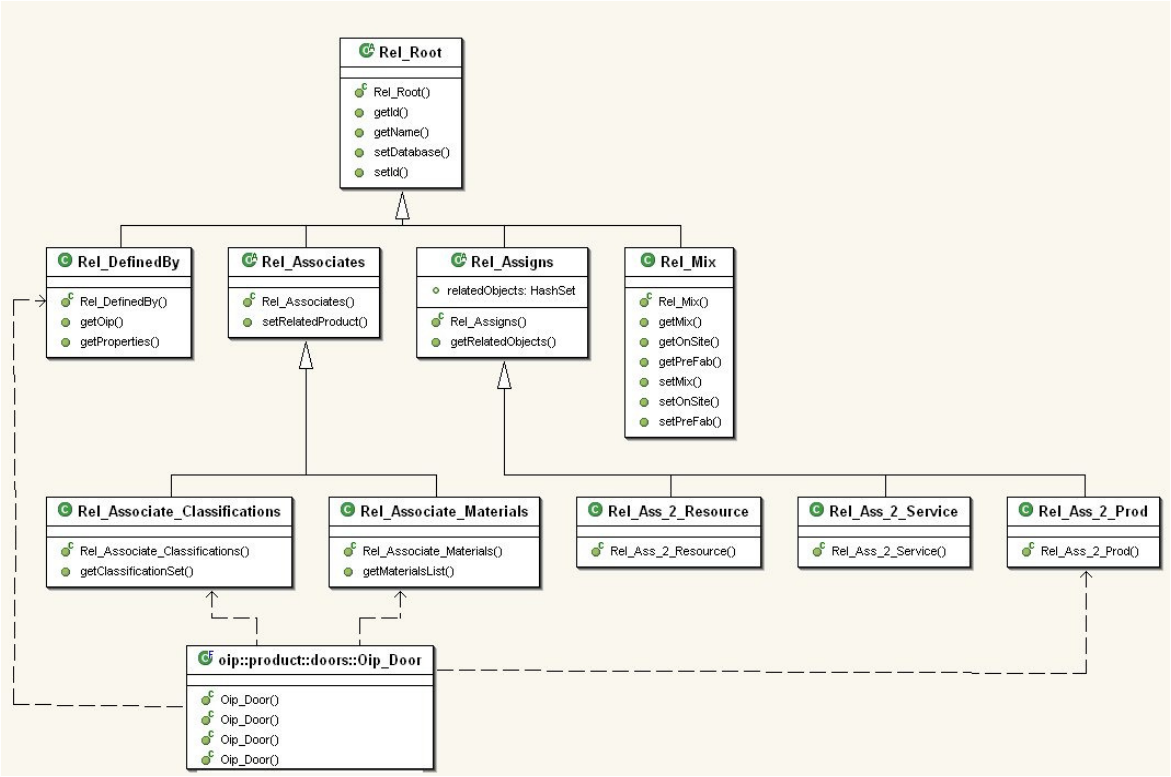


Figure 5.4 The UML diagram of the OIP kernel relations

of the model together. The Rel_Assigns is differentiated to three types of assignments that link instances of products, services and resources together. An example of such relations is the assignment of a door to a wall. Meanwhile, the Rel_Associates links the products together with their constituent materials through its subtype Rel_Associates_Materials. Moreover, it links the classifications to all OIP objects through the subtype Rel_Associates_Classification. The Rel_DefinedBy established the link between the OIP products and their type definitions and property sets.

The UML diagram in figure 5.5 shows the OIP resources data structure, where properties, equipment, materials and labour are all subtypes of the "*Resource"* entity. The properties are differentiated to simple and complex properties. In the meantime, a complex property references a *Set* that contains one or more simple properties. The EXPRESS-G diagram in figure 4.9. in chapter four -that discusses the proposed theoretical solution of the developed prototype- represents the theoretical design intentions that are implemented in this chapter. Readers interested in the technicalities of the solution are advised to explore the the code of the classes in the UML diagrams in appendix "C" inside the package "oip" and under the same names as stated in the diagrams.

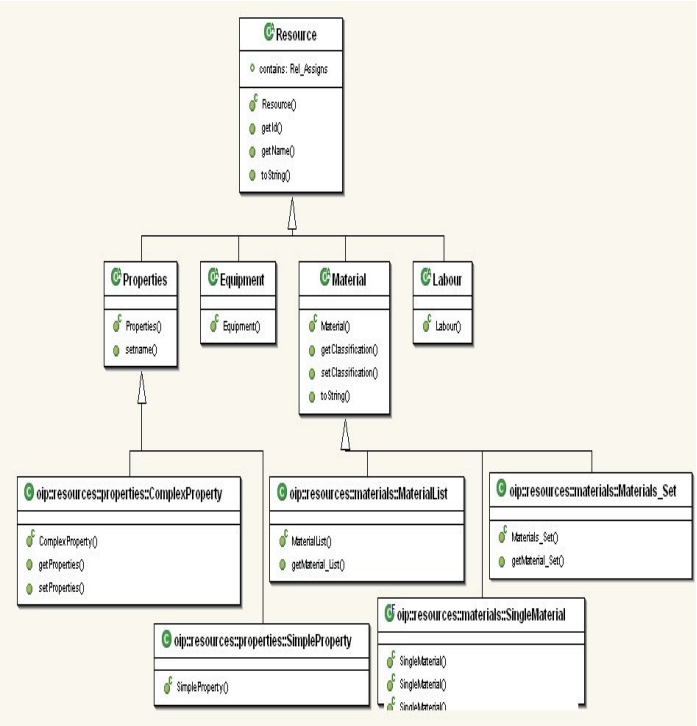


Figure 5.5 The UML Diagram of the OIP resources

5.3.2 The OIP Database relational Model

The object oriented model is only instantiated at run time. Hence, data persistence was considered to be an important problem for this work. To solve this problem, three main alternative solutions were investigated. First is the serialization of the object oriented model in to a file. Second was to develop an object oriented model in an object oriented database, where the EDM (EXPRESS Data Manager) database was considered together with using its Java API, the EXPRESS-X and the EXPRESS-Q mapping and query languages. The third alternative was to use a normal relational database, where SQL could be implemented for queries.

The first solution was tried and rejected due to the fact that it is not able to hold the huge amount of information that an organization like the OIP is expected to have. Moreover and more

important is that all the stored information has to be downloaded during run time (de-serialized), which is of course not suitable for such kind of applications.

The second solution is feasible and was tried in the early beginning stages, however, the third solution was much simpler and had the advantages of being fully independent from any commercial software application and the use of SQL could satisfy all the query needs that build the objects in the object oriented model at run time on demand (only the ones that are needed).

As a general rule in the design of the relational database model, all the used objectified relationship classes that reside in the kernel of the object oriented model where mapped one to one to cross reference tables in the relational model as shown in figure 5.6 and appendix C (databases/OIP), where the OIP identifier is used as a foreign key of the tables to enable SQL queries.

The relational model consists of twenty tables as shown in figure 5.6. Four of them represent the relations in the OIP kernel, seven tables (that begin with "temp_") are temporary tables that are used to perform sub-queries, as they are not directly supported by Microsoft Access. These tables are always empty. The values in these tables are deleted after performing the sub-queries.

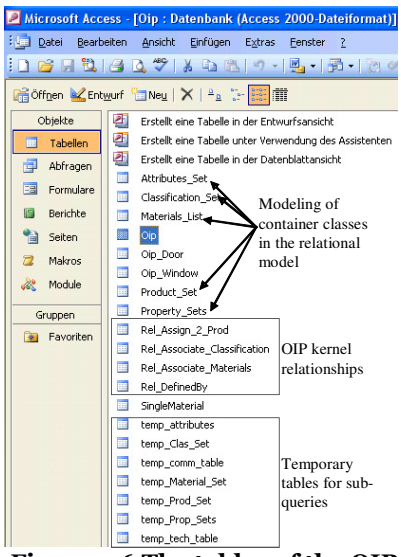
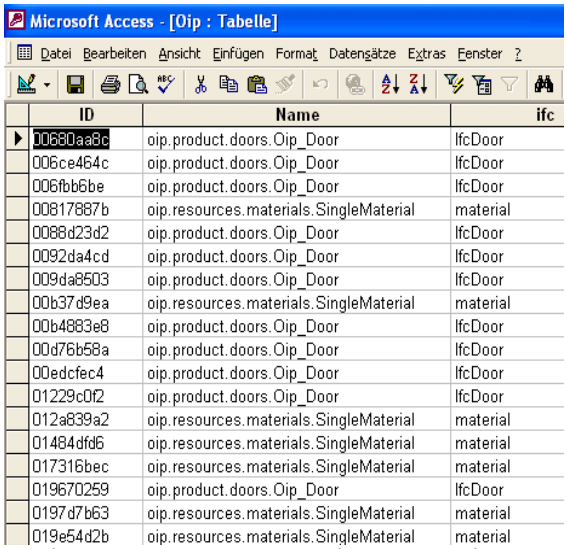


Figure 5.6 The tables of the OIP relational model



ID	Name	ifc
00680aa8c	oip.product.doors.Oip_Door	IfcDoor
006ce464c	oip.product.doors.Oip_Door	IfcDoor
006fbb6be	oip.product.doors.Oip_Door	IfcDoor
00817887b	oip.resources.materials.SingleMaterial	material
0088d23d2	oip.product.doors.Oip_Door	IfcDoor
0092da4cd	oip.product.doors.Oip_Door	IfcDoor
009da8503	oip.product.doors.Oip_Door	IfcDoor
00b37d9ea	oip.resources.materials.SingleMaterial	material
00b4883e8	oip.product.doors.Oip_Door	IfcDoor
00d76b58a	oip.product.doors.Oip_Door	IfcDoor
00edcfec4	oip.product.doors.Oip_Door	IfcDoor
01229c0f2	oip.product.doors.Oip_Door	IfcDoor
012a839a2	oip.resources.materials.SingleMaterial	material
01484dfd6	oip.resources.materials.SingleMaterial	material
017316bec	oip.resources.materials.SingleMaterial	material
019670259	oip.product.doors.Oip_Door	IfcDoor
0197d7b63	oip.resources.materials.SingleMaterial	material
019e54d2b	oip.resources.materials.SingleMaterial	material

Figure 5.7 The OIP table in the relational model

Figure 5.8 represents the relations between the entities (tables) in the relational model. The table *Oip* contains the OIP technical unique identifier as its foreign key. It also contains the full name of the Oip product including the package name as seen in figure 5.7. This helps in creating a new instance of the product class in the object oriented model at run time (as needed). Finally, it contains the name of the IFC entity that is represented by this OIP (e.g. IfcDoor, IfcWindow and so forth).

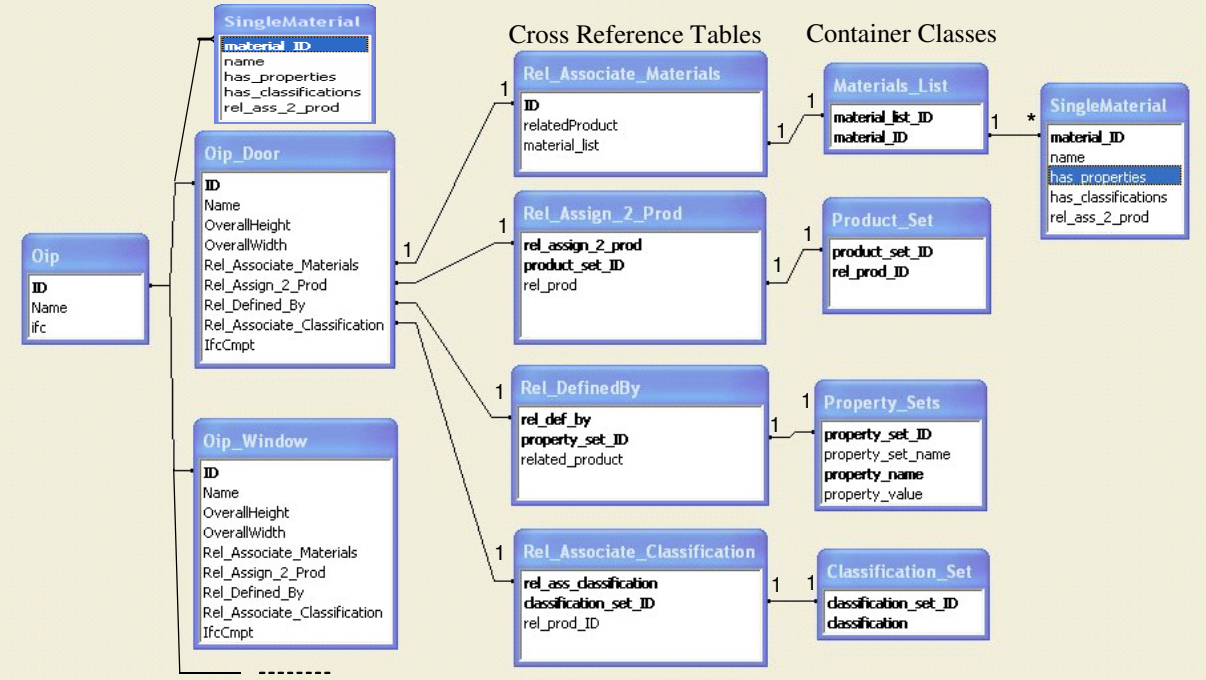
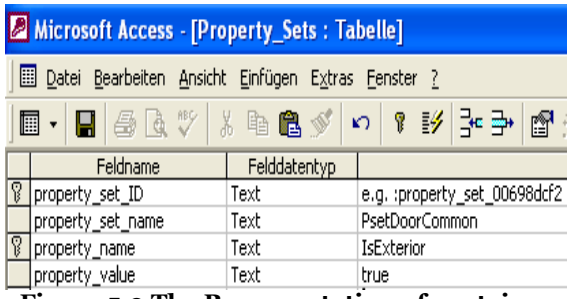


Figure 5.8 OIP relational model

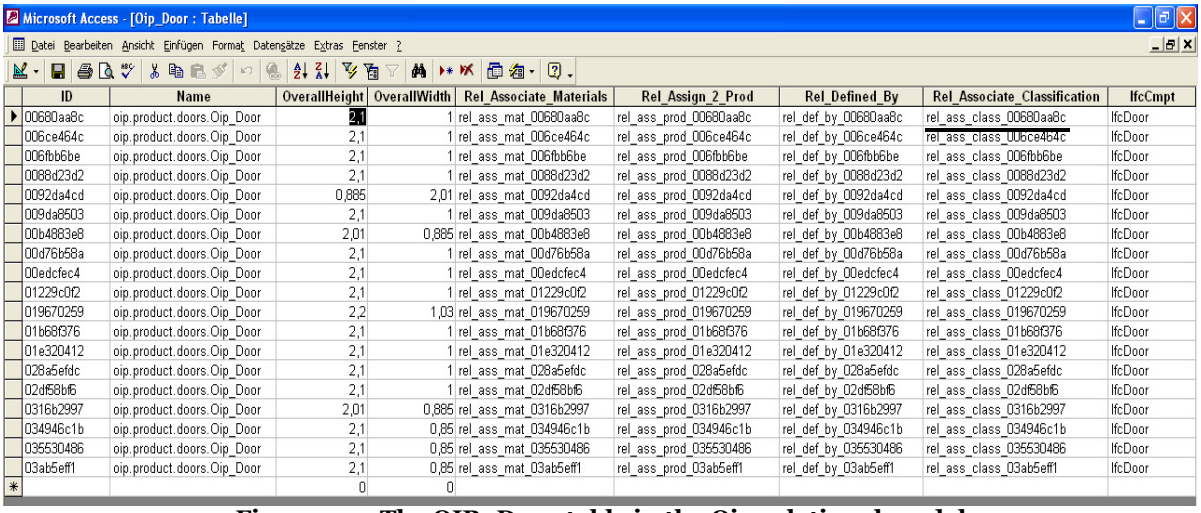
Figure 5.8 also shows tables that represent examples of Oip products such as doors, windows and materials. By taking Oip_Door as an example, it could be seen from figures 5.8 and 5.10 that the Oip_Door table has references to the cross reference tables that represent the objectified relationship classes in the kernel of the run time object oriented model. The elements in the table Oip can be any construction product or material. It is also worth mentioning that a product can have references to its materials and other constituent products through the cross reference tables Rel_Associate_Materials and Rel_Assign_2_Prod respectively, in addition to classifications and property sets, as shown in figure 5.8. The reader can refer to the tables of the above mentioned entities in appendix C (databases/Oip).

Another problem was the mapping of the container classes e.g. sets and lists to the relational model. This was done through a table that contains two foreign keys at the same time as shown in figures 5.9 and 5.11. Hence, all properties that have the same property set ID belong to the same property set and are related to the product through the *RelDefineBy* cross reference table as shown in figure 5.8.



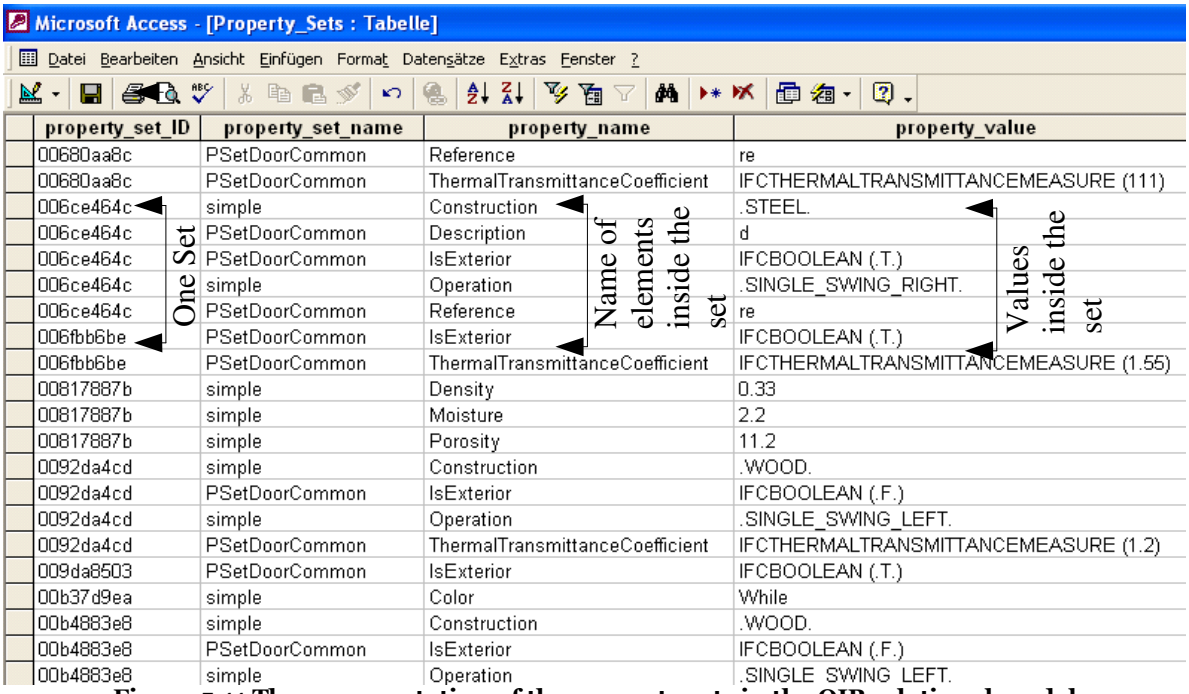
Feldname	Felddatentyp	
property_set_ID	Text	e.g. :property_set_00698dcf2
property_set_name	Text	PsetDoorCommon
property_name	Text	IsExterior
property_value	Text	true

Figure 5.9 The Representation of container classes in the relational model



ID	Name	OverallHeight	OverallWidth	Rel_Associate_Materials	Rel_Assign_2_Prod	Rel_Defined_By	Rel_Associate_Classification	IfcCmpt
00680aa8c	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_00680aa8c	rel_ass_prod_00680aa8c	rel_def_by_00680aa8c	rel_ass_class_00680aa8c	IfcDoor
006ce464c	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_006ce464c	rel_ass_prod_006ce464c	rel_def_by_006ce464c	rel_ass_class_006ce464c	IfcDoor
006fbb6be	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_006fbb6be	rel_ass_prod_006fbb6be	rel_def_by_006fbb6be	rel_ass_class_006fbb6be	IfcDoor
0088d23d2	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_0088d23d2	rel_ass_prod_0088d23d2	rel_def_by_0088d23d2	rel_ass_class_0088d23d2	IfcDoor
0092da4cd	oip.product.doors.Oip_Door	0,885	2,01	rel_ass_mat_0092da4cd	rel_ass_prod_0092da4cd	rel_def_by_0092da4cd	rel_ass_class_0092da4cd	IfcDoor
009da8503	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_009da8503	rel_ass_prod_009da8503	rel_def_by_009da8503	rel_ass_class_009da8503	IfcDoor
00b4883e8	oip.product.doors.Oip_Door	2,01	0,885	rel_ass_mat_00b4883e8	rel_ass_prod_00b4883e8	rel_def_by_00b4883e8	rel_ass_class_00b4883e8	IfcDoor
00d76b58a	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_00d76b58a	rel_ass_prod_00d76b58a	rel_def_by_00d76b58a	rel_ass_class_00d76b58a	IfcDoor
00edcfec4	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_00edcfec4	rel_ass_prod_00edcfec4	rel_def_by_00edcfec4	rel_ass_class_00edcfec4	IfcDoor
01229c0f2	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_01229c0f2	rel_ass_prod_01229c0f2	rel_def_by_01229c0f2	rel_ass_class_01229c0f2	IfcDoor
019670259	oip.product.doors.Oip_Door	2,2	1,03	rel_ass_mat_019670259	rel_ass_prod_019670259	rel_def_by_019670259	rel_ass_class_019670259	IfcDoor
01b68f376	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_01b68f376	rel_ass_prod_01b68f376	rel_def_by_01b68f376	rel_ass_class_01b68f376	IfcDoor
01e320412	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_01e320412	rel_ass_prod_01e320412	rel_def_by_01e320412	rel_ass_class_01e320412	IfcDoor
028a5efdc	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_028a5efdc	rel_ass_prod_028a5efdc	rel_def_by_028a5efdc	rel_ass_class_028a5efdc	IfcDoor
02df58bf6	oip.product.doors.Oip_Door	2,1	1	rel_ass_mat_02df58bf6	rel_ass_prod_02df58bf6	rel_def_by_02df58bf6	rel_ass_class_02df58bf6	IfcDoor
0316b2997	oip.product.doors.Oip_Door	2,01	0,885	rel_ass_mat_0316b2997	rel_ass_prod_0316b2997	rel_def_by_0316b2997	rel_ass_class_0316b2997	IfcDoor
034946c1b	oip.product.doors.Oip_Door	2,1	0,85	rel_ass_mat_034946c1b	rel_ass_prod_034946c1b	rel_def_by_034946c1b	rel_ass_class_034946c1b	IfcDoor
035530486	oip.product.doors.Oip_Door	2,1	0,85	rel_ass_mat_035530486	rel_ass_prod_035530486	rel_def_by_035530486	rel_ass_class_035530486	IfcDoor
03ab5eff1	oip.product.doors.Oip_Door	2,1	0,85	rel_ass_mat_03ab5eff1	rel_ass_prod_03ab5eff1	rel_def_by_03ab5eff1	rel_ass_class_03ab5eff1	IfcDoor
		0	0					

Figure 5.10 The OIP_Door table in the Oip relational model



property_set_ID	property_set_name	property_name	property_value
00680aa8c	PSetDoorCommon	Reference	re
00680aa8c	PSetDoorCommon	ThermalTransmittanceCoefficient	IFCTHERMALTRANSMITTANCEMEASURE (111)
006ce464c	simple	Construction	.STEEL.
006ce464c	PSetDoorCommon	Description	d
006ce464c	PSetDoorCommon	IsExterior	IFCBOOLEAN (.T.)
006ce464c	simple	Operation	.SINGLE_SWING_RIGHT.
006ce464c	PSetDoorCommon	Reference	re
006fbb6be	PSetDoorCommon	IsExterior	IFCBOOLEAN (.T.)
006fbb6be	PSetDoorCommon	ThermalTransmittanceCoefficient	IFCTHERMALTRANSMITTANCEMEASURE (1.55)
00817887b	simple	Density	0.33
00817887b	simple	Moisture	2.2
00817887b	simple	Porosity	11.2
0092da4cd	simple	Construction	.WOOD.
0092da4cd	PSetDoorCommon	IsExterior	IFCBOOLEAN (.F.)
0092da4cd	simple	Operation	.SINGLE_SWING_LEFT.
0092da4cd	PSetDoorCommon	ThermalTransmittanceCoefficient	IFCTHERMALTRANSMITTANCEMEASURE (1.2)
009da8503	PSetDoorCommon	IsExterior	IFCBOOLEAN (.T.)
00b37d9ea	simple	Color	While
00b4883e8	simple	Construction	.WOOD.
00b4883e8	PSetDoorCommon	IsExterior	IFCBOOLEAN (.F.)
00b4883e8	simple	Operation	.SINGLE_SWING_LEFT.

Figure 5.11 The representation of the property sets in the OIP relational model

5.3.3 Mapping the OIP Object Oriented model to a relational Model

The mapping between the two models is done using SQL queries. In the scope of this work, two types of queries are supported. The first type builds up the product instance together with all its attributes by using the OIP technical identifier

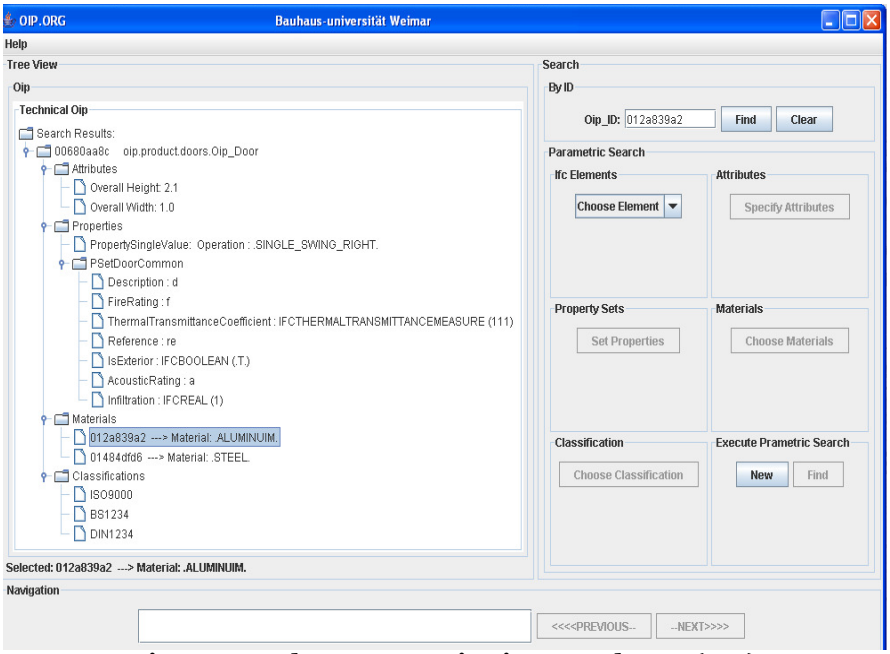


Figure 5.12 The OIP Organisation search GUI (UI1)

of the product as a search parameter as shown at the top right of figure 5.12. The figure together with the video demonstration in appendix C (demos/ UI1 / OIP_ID) show how the user interface (UI1) displays a tree view of the product, its materials, classifications, property sets and its constituent products (if they exits). Furthermore, the user can navigate through the tree and select any of the constituents. If this constituent is a product or a material then its OIP is displayed automatically in the search filed as shown in figure 5.12 and the video demo. By pressing the "Find" button, a ready made SQL query that is encapsulating behind the graphical user interface is executed in the relational database and a new product is created instantly (in the object oriented model) and its tree structure is displayed. The code for searching the database by using the OIP identifier and constructing the objects in the object oriented model is shown in the classes "Query" and "QueryLang" in the package "access.database.cmds" and in Appendix C.

The second kind of search is a parametric search, were the user defines the values of the attributes of the product (as a single value or as an interval), together with the classifications,

materials, property sets and constituent materials or products, as shown in figure 5.13 and in the video demonstration in (appendix C/demos/UI1/OIP_Param).

It is worth mentioning that the software performs such queries over the Internet using the Java RMI, Java Applets, and Java JDBC technologies (Resse 2000), as shown in the code in the package "remote", in appendix C.

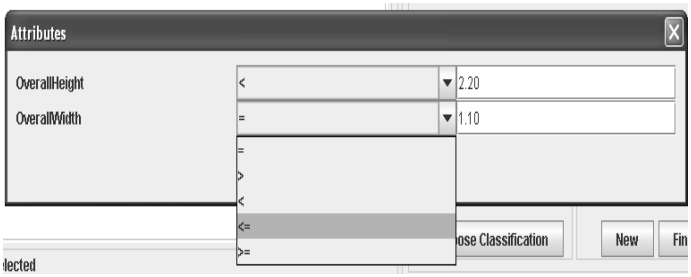


Figure 5.13 The definition of a value interval for parametric searches

Finally the software enables the navigation over the result set (*java.sql.ResultSet*) resulting from the SQL query, through the previous and next buttons, as shown at the bottom right of figure 5.12 and in the video demonstration in (appendix C/demos/UI1/RS_Navi). These actions regulate the transfer of data on the Internet by displaying a maximum of five hits at a time, otherwise the returned result set could include all the elements inside the OIP organisation. This is done by wrapping the *ResultSet* returned from the query by a buffer that supports the forward and backward iterations (the code is found at "access.database.cmds.DB_Buffer" in appendix C).

5.4 Portal Database

The suppliers and brand-name holders register themselves together with their products' commercial properties and references to the technical OIPs at the portal website as shown in figure 5.1, the graphical user interfaces' snapshots in figures 5.14 and 5.15 and the video demonstration in (appendix C/demos/UI5/*). Figure 5.17 shows a UML diagram that represents the runtime object oriented model of both the commercial properties of the construction product and its supplier(s). It can be noticed that a supplier can have references to more than one product at the same time.

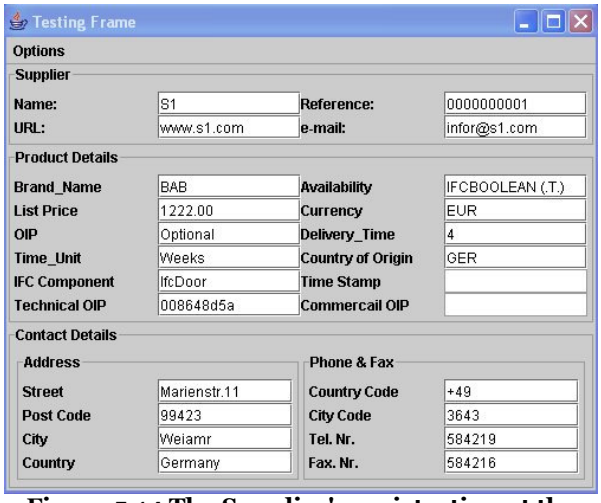


Figure 5.14 The Supplier's registration at the Portal Website

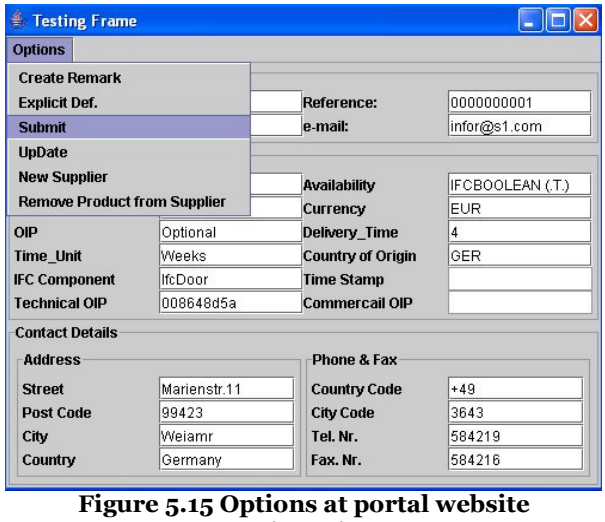


Figure 5.15 Options at portal website registration

In the scope of the given example in this chapter (in tables 5.1 and 5.2), the same product (OIP identifier: "008648d5a") is provided by eight suppliers, as shown in figure 5.16. The first six provide the product under the same brand name with typically the same properties. The last two suppliers sell the product under different brand names and commercial properties. Consequently, the product has the same technical OIP identifier (the first nine digits) and

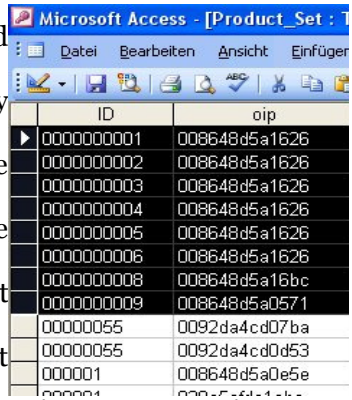


Figure 5.16Suppliers and Products

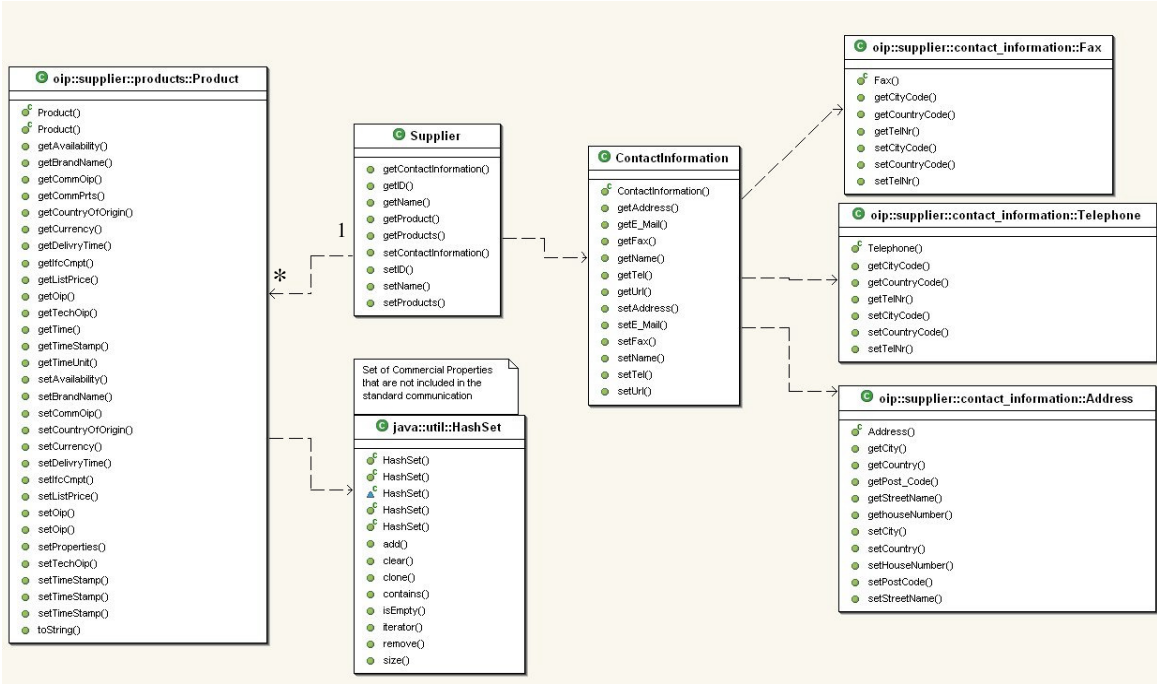


Figure 5.17 The runtime object oriented model of the portal website database

different commercial identifiers (the last four digits.)

Figure 5.18 and Appendix C (databases/Supplier) show the design of the persistent relational model of the database. It consists of eight tables that represent the commercial properties of the

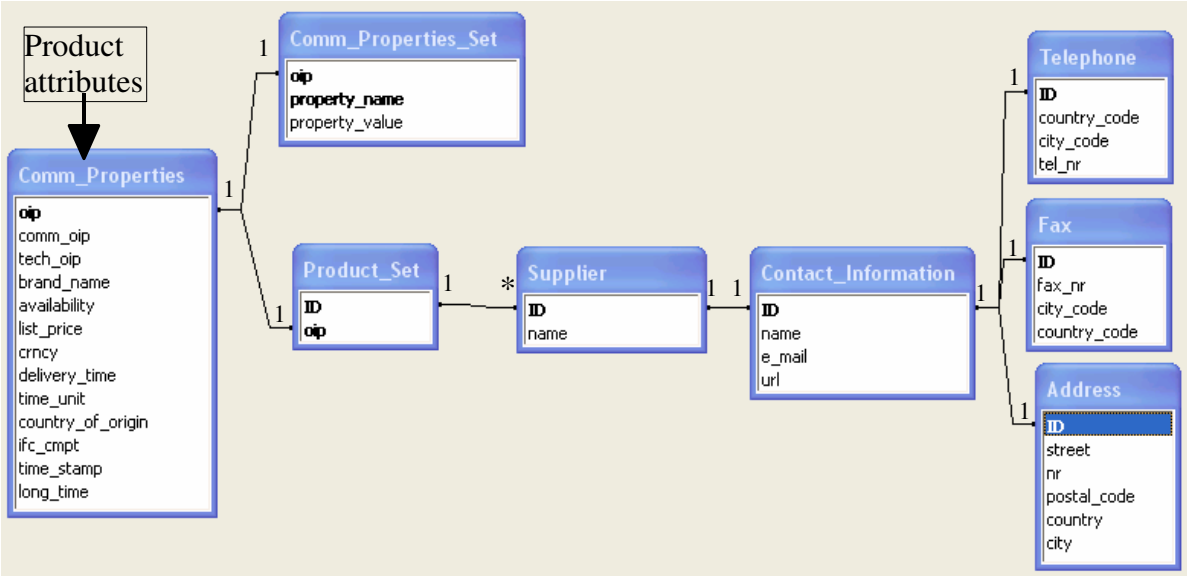


Figure 5.18 The design of the commercial OIP relational model

construction product and the details of the supplier(s). The options that are available to the supplier through the user interface in figure 5.15 enable the registration of multiple-suppliers with the same product. Many suppliers can sell the same product with the same OIP as long as it is sold under the same brand name. In such cases the brand name holder would be most probably responsible for the commercial OIP. In other cases, where the same product is sold under different brand names with different commercial properties and services. The technical part of the OIP identifier remains constant. However, the commercial part of the identifier shall be different, resulting in different OIP overall identifiers, i.e. (technical + commercial), as described earlier in the theory in chapter four in section 4.2.5.1 and figure 4.7.

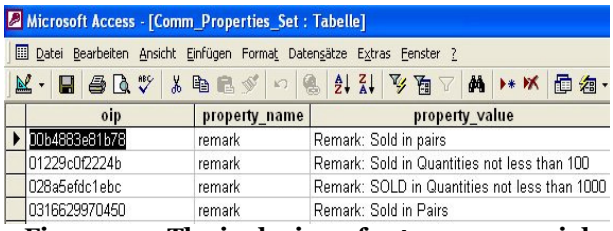
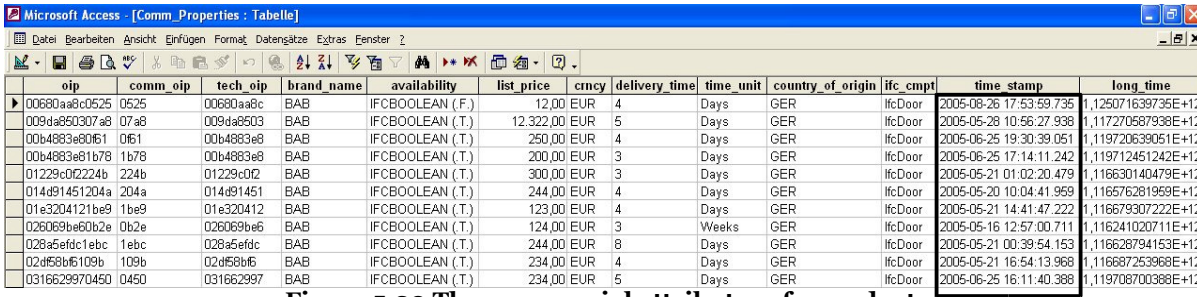


Figure 5.19 The inclusion of extra commercial properties

The software also supports updating the commercial information by giving a time stamp to the current product data version. The user at the client side can consequently check at any time if the information on his/her side is up-to-date or not. In case, where a newer version exists, then the information is updated accordingly in the IFC model by using software tools that are developed at


Microsoft Access - [Comm_Properties : Tabelle]

Datei Bearbeiten Ansicht Einfügen Format Datensätze Extras Fenster ?

oip	comm_oip	tech_oip	brand_name	availability	list_price	crncy	delivery_time	time_unit	country_of_origin	ifc_cmpt	time_stamp	long_time
00680aa8c0525	0525	00680aa8c	BAB	IFCBOOLEAN (.F.)	12,00	EUR	4	Days	GER	IfcDoor	2005-08-26 17:53:59.735	1,125071639735E+1
009da850307a8	07a8	009da8503	BAB	IFCBOOLEAN (.T.)	12.322,00	EUR	5	Days	GER	IfcDoor	2005-05-28 10:56:27.938	1,117270587938E+1
00b4883e80f61	0f61	00b4883e8	BAB	IFCBOOLEAN (.T.)	250,00	EUR	4	Days	GER	IfcDoor	2005-06-25 19:30:39.051	1,119720639051E+1
00b4883e81b78	1b78	00b4883e8	BAB	IFCBOOLEAN (.T.)	200,00	EUR	3	Days	GER	IfcDoor	2005-06-25 17:14:11.242	1,119712451242E+1
01229c0f2224b	224b	01229c0f2	BAB	IFCBOOLEAN (.T.)	300,00	EUR	3	Days	GER	IfcDoor	2005-05-21 01:02:20.479	1,116630140479E+1
014d91451204a	204a	014d91451	BAB	IFCBOOLEAN (.T.)	244,00	EUR	4	Days	GER	IfcDoor	2005-05-20 10:04:41.959	1,116576281959E+1
01e3204121be9	1be9	01e320412	BAB	IFCBOOLEAN (.T.)	123,00	EUR	4	Days	GER	IfcDoor	2005-05-21 14:41:47.222	1,116679307222E+1
026069be60b2e	0b2e	026069be6	BAB	IFCBOOLEAN (.T.)	124,00	EUR	3	Weeks	GER	IfcDoor	2005-05-16 12:57:00.711	1,116241020711E+1
028a5efdc1ebc	1ebc	028a5efdc	BAB	IFCBOOLEAN (.T.)	244,00	EUR	8	Days	GER	IfcDoor	2005-05-21 00:39:54.153	1,116628794153E+1
02df58bf6109b	109b	02df58bf6	BAB	IFCBOOLEAN (.T.)	234,00	EUR	4	Days	GER	IfcDoor	2005-05-21 16:54:13.968	1,116687253968E+1
0316629970450	0450	031662997	BAB	IFCBOOLEAN (.T.)	234,00	EUR	5	Days	GER	IfcDoor	2005-06-25 16:11:40.388	1,119708700388E+1

Figure 5.20 The commercial attributes of a product

the client's side. The commercial product attributes that are represented in the product tree view in figure 5.21 and in the table *"Comm_Properties"* in figure 5.20, represent a sample of the commercial attributes of product data. These attributes were selected to be included in this work as a result of being common in real on line suppliers' catalogues and research projects from the literature. Furthermore, the software enables adding an arbitrary number of additional textual remarks and properties to the product to cover any need for extra information or remarks that could not be included in the standard data communication, this can be seen on the right hand side of the snapshot in figure 5.21 and in the video demos in (appendix C/demos/UI2/*). These properties are included in the *HashSet* that is referenced by the product, as seen in the object oriented model in figure 5.17 and in the table Comm_Properties_Set in the relational model as shown in figures 5.18.and 5.19. It is also worth mentioning that a mapping between the persistent relational model and the runtime object oriented model exists to build the product at run time, as a result of queries that are submitted to the portal website.

5.4.1 Web Server

A software tool with the graphical user interface (UI2)- as shown in figures 5.1 and 5.21- is developed to find out all the needed commercial information about a product from a server that runs at the portal website, provided that an OIP identifier is available. In the meantime, all needed information can be merged to the building information model at the client's side in a drag

and drop environment, as it is discussed later in detail in this chapter in section 5.6.3. Moreover, parametric searches are supported from the client side, where the construction products' parameters are defined. This is explained in detail in sections 5.6.1 that describes the conduction of parametric searches.

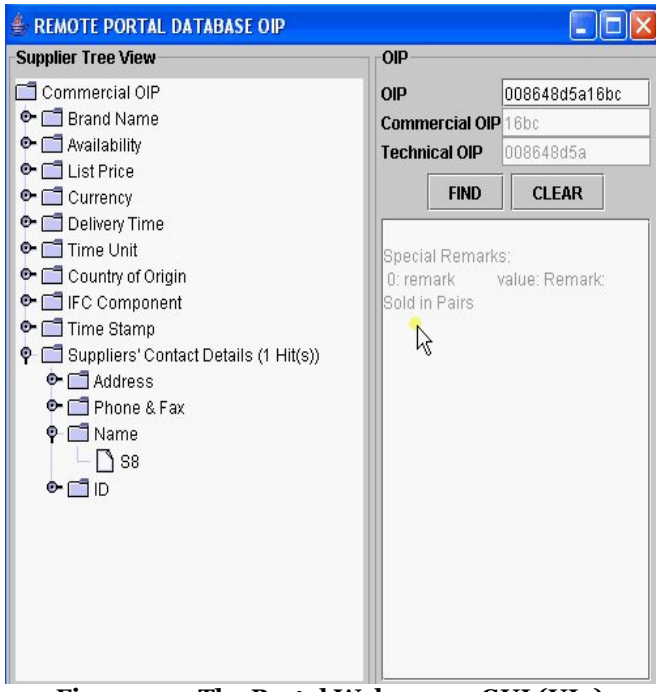


Figure 5.21 The Portal Web server GUI (UI2)

5.5 Client Side

The software tools that are developed at the client's side represent the key enabler for bridging the technical barriers that prevent mapping, merging and updating construction product data into the IFC model in a distributed network application. It is worth mentioning that some of these tools are of general use and could be utilized in applications other than this work.

The client specifies his search parameters by extracting them from the CAD/IFC model that is originally produced using a commercial CAD application, in addition to explicitly specifying his own. This is done by the client through the graphical user interface UI4 in figure 5.1 and the video demonstrations in (appendix C/demos/UI4/*). In other words, it is a process of establishing a *requirements model*, by the specifier, according to the product's attributes and property sets, which is later transferred to one or more *design models*.

The coming sections describe the development of such tools. Among these tools are a STEP-P21 parser and an IFC2x Java interpreter, where the IFC model is built in the form of early and late binding Java classes, as shown in sections 5.5.1 and 5.5.2. In addition, the software tools are capable of providing multiple views of the IFC model, such as the tree view, the CAD view and the STEP view. These views are explained in detail in section 5.5.3. Furthermore, the tools enable

operations that can be executed on the IFC model such as instantiation, updates or deletion of information, bearing in mind the optimisation of the IFC model's size as discussed in section 5.5.4. Finally, the tools enable the client (user) to map and merge any needed product data on-line to the IFC model by using a drag and drop environment. This is considered the process by which the model is changed from being a requirements model to being a design model. Moreover, checks for any updates to the commercial product data can be done at any point in time, where the updated product information can by synchronized with the building information model (IFC). This is described in detail in section 5.6.

Section 5.7 discusses work flow management aspects that were encountered by the author, after exporting the IFC models that are instantiated with construction product data. The discussion addresses the problem of data loss in addition to ways and means to rectify such problem.

5.5.1 Parsing STEP ISO 10303 – P21 Files

A major problem facing the implementation of IFC in university research projects is the process of parsing STEP files and the instantiation of the IFC Model, which is defined in EXPRESS ISO-10303-P11 language. In industry contexts, there are several generic EXPRESS based object oriented databases that are capable of reading, updating, writing and mapping STEP models that might be written against different EXPRESS schemata. However, the costs of such relatively new technologies, at the time of writing this work, are extremely high, e.g EDM Express Data Manager (EPM 2004). Furthermore, it enforces any software development to be dependent on a specific commercial software tool that requires a considerable amount of time to get used to its environment and to have a good grasp of its APIs. Moreover, in order to perform the above mentioned operations and queries, mappings schemata have to be written in EXPRESS-X ISO 10303 P-14 by the user. In the meantime, it should be mentioned that the main aim behind developing the parser is not to duplicate functionalities that are already made available by commercial software applications. On the contrary, the parser and the interpreter are just members of a group of tools that perform together functionalities that are not supported by a

single commercial software application at the time of writing this work. The developed tools are integrated together to perform functionalities such as the visualisation of the IFC model in different forms, extraction of search parameters from CAD/IFC models, the explicit definition of property sets, conduction of parametric searches for products over the Internet, product data retrieval, checking for updates of product data, the mapping and merging of product data on line by the help of remote graphical user interfaces and so forth.

For many researchers, IFC is considered to be not more than a means for data exchange between commercial software applications. It was found that one of the biggest barriers standing between researchers and the IFC model is how to push the model itself from the theory in the IAI[10] documentation to the practice of implementation. By exploring the Parser generation technologies (Java Compiler Compiler), (Firmenich 2004), the idea of creating a STEP ISO-10303-P21 parser (Nour 2004) was no longer an impossible task. It should be also mentioned that the author is not a computer science specialist or a professional programmer. This shows that the technology used for this purpose is user friendly and well documented. Nevertheless, a good understanding of the EXPRESS language and the STEP standard are considered to be essential prerequisites for developing such parsers.

This section tries to give a very brief introduction to the STEP, IFC, and EXPRESS (ISO 10303-11 EXPRESS 1994) technologies. However, it is not considered by any means to be a substitute for the original documentation. The main focus is on the steps of creating a STEP parser and the alternative options and decisions that could be made to suit different purposes behind the parser and interpreter developments.

5.5.1.1 Analysis of a STEP file

STEP is considered to be the standard for exchange of product model data. It is the means by which data defined by an EXPRESS schema can be transferred from one application to another.

10 IAI International Alliance for Interoperability, www.iai-international.org/iai_international/

STEP is a straightforward ASCII file format for exchanging EXPRESS-defined data sets. The exchange file format is Part 21 of the standard (ISO 10303 1994). Figure (5.22) shows that a STEP file consists of two sections; first is the HEADER section and then the DATA section. Both sections end with an '*ENDSEC;*' statement and are encapsulated between a starting '*ISO-10303-21;*' statement and an '*END-ISO-10303-21;*' statement. The HEADER section of a STEP part 21 file includes identifying information about the file such as a textual description of the file, its name, the time stamp, the author(s) and organisation name(s), the name of the EXPRESS schema and so forth. An example of a header is shown in appendix A1.

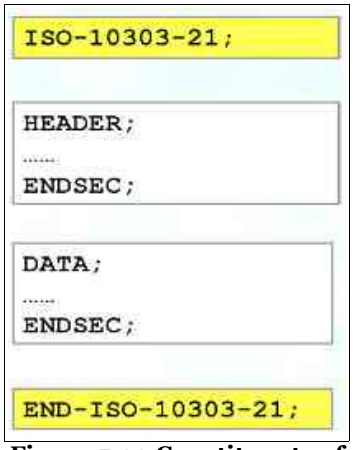


Figure 5.22 Constituents of a STEP file, (Nour 2004)

The DATA section consists of an arbitrary number of IFC elements as shown in figure (5.23). The figure also represents a real extract from an IFC (STEP) file - found in appendix A1 - that represents an IfcWall and its IfcMaterial attributes. Entity instances are normally written using an *"internal mapping"* from EXPRESS to STEP where the name of the entity type is followed by a list of attributes in superclass-to-subclass order. It can be noticed that the attributes of the wall can not be followed to reach the material. Both attributes #56 and #54 of the wall are references to the placement and representation of the wall respectively. This is due to the fact that the inverse attributes of the wall are not mapped to the STEP file[11]. Hence, the only means to match a wall and its material attribute is through the IfcRelAssociatesMaterial (#58) that references both the wall (#57)and its material attribute (#37). It can also be seen that the attributes can be classified as String, Numbers (Float, Double or Integer), references to other elements, null references that are represented as [$] and finally container classes that are nested between extra parenthesis.

11 The reader can refer to the EXPRESS definition of the entity IfcWallStandardCase to see the INVERSE relationship that refers to the associated material.(*HasAssociations*).

5.5.1.2 The development of the Parser

The first step in developing the parser was identifying the syntax of the STEP file, then defining the grammar. The first step was determined as a result of the analysis process of the STEP physical file. The second step was done by writing down a grammar of the step file. Appendix A2 shows the defined grammar (a jjdoc output of the STEP_PARSER.jj[12] file for the NON-TERMINALS). It represents the grammar of the STEP file, starting with the HEAD section and moving to the body or DATA section and ending with the END_ISO_STEP statement. The reader can refer to (Nour 2004) for a detailed technical description of the parser.

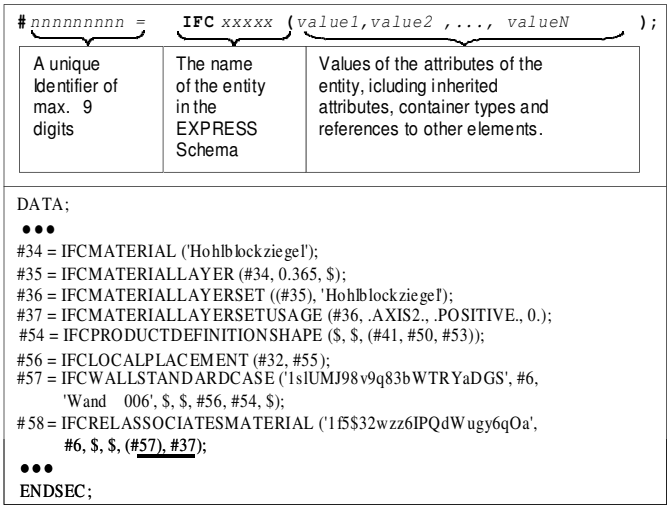


Figure 5.23 The Analysis of the STEP file, (Nour 2004)

At the end of the parsing process, the IFC model is represented in the form of a three dimensional array, as shown in figure 5.24. The first dimension of the array contains all the IfcElements (1st array), each IFC element points to an array containing its arguments (2nd array) and finally some argument values are references to container classes i.e. They are represented through the third dimension (3rd array). Now the STEP

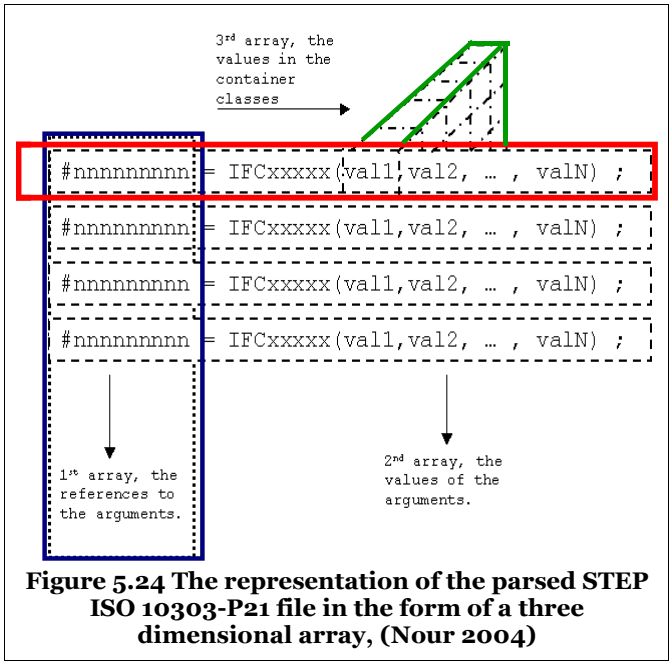


Figure 5.24 The representation of the parsed STEP ISO 10303-P21 file in the form of a three dimensional array, (Nour 2004)

12 The jj file is found in Appendix C at the package step_parser

code should have already been parsed and is ready for interpretation by Java.

5.5.2 IFC Interpreter

The fact that STEP is a kind of mapping of objects defined in EXPRESS cannot be ignored. In other words, each STEP file is written against an EXPRESS schema. This means that some attributes -as earlier mentioned- can be absent in the STEP file (e.g. the derived and inverse attributes). Moreover, Java is a programming and modeling language, whereas EXPRESS IS NOT a programming language. There are lots of differences that can be pointed out between the two languages. Among these differences are the support for multiple inheritance, different types of container classes, logical, optional and Inverse attributes.

STEP physical files are tightly bound to the EXPRESS schemata they were written against. Because the attribute values and their ordering are determined from the EXPRESS schema, changes to the schema may cause problems with files written against the original version. This is typically the case when trying to shift from using one version of the the IFC model to another. As there is not enough space to discuss all of such aspects, in the context of this work, only important issues that are encountered through the process of creating the interpreter are discussed. The EXPRESS language is also discussed in detail in order to demonstrate how it is mapped to Java in the software application.

5.5.2.1 EXPRESS

The history of EXPRESS begins in 1982 as the Product Data Definition Interface (PDDI) project was established to specify an interface between design and manufacturing for product definitions (Wilson 1987). During this project, Douglas Schenck at McDonnald Douglas developed a data definition language called DSL (Schenck et al 1994). This language was the basis for EXPRESS. The language went through many revision and feedback stages that influenced its design; EXPRESS acquired design concepts from Ada, Algol, C, C++, Euler, Modula-2, Pascal, PL/I, and SQL. The language developed an object oriented flavor, with objects, inheritance, and a rich

collection of types with the aim of describing information requirements and correctness conditions necessary for meaningful data exchange. In December 1983, the International Standards Organization (ISO) formed the TC184/SC4 committee that began working on the Standard for Exchange of Product Model Data (STEP) with the aim of defining an integrated product information model. This model defines specifications for the representation and exchange of digital product information. Hence, a product data standard that incorporated experience from national efforts such as IGES (IGES 1980), VDAF (VDAF 1986), SET (SET 1985), CAD (Kroszynski et al 1989) and PDDI (Birchfiel 1985), (PDDI 1984) was defined. For further information about STEP APs (Application Protocols) and IRs (Integrated Resources) the reader can consult the publications of the ISO TC184/SC4 committee.

EXPRESS is a data modelling language that allows unambiguous data definition and specification of constraints on the defined data. It was published as ISO 10303 P-11 and used for most product data standards such as: ISO 10303 (STEP), ISO 13584 (PLIB), ISO 15331 (MANDATE), ISO 15926 (OIL&GAS), IFC, EDIF and so forth. It is readable to humans and fully computer interpretable. Although, EXPRESS is not a programming language, the ISO 10303 defines straight forward implementation forms.

It is worth also mentioning that there are EXPRESS 'dialects' within ISO 10303. These are the EXPRESS ISO 10303 p11, which represents the textual notation, the EXPRESS-G that represents the graphical notation, the EXPRESS-I (ISO 10303 -P12) that represents the instantiation language, EXPRESS-X (ISO 10303-p14) that represents the mapping and viewing language. In addition to some proprietary dialects such as EXPRESS-C, EXPRESS +, EXPRESS-V and EXPRESS-M (EPM 2002, chap 2).

An EXPRESS information model is organized into schemata. In this work, the *IFC2x* Schema is

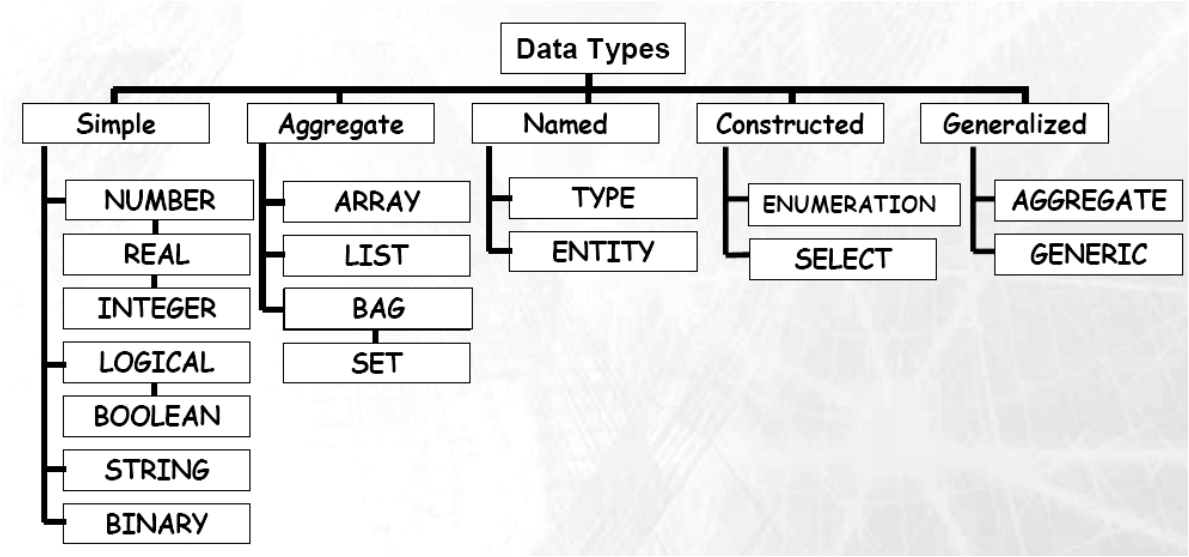


Figure 5.25 EXPRESS ISO 10303-P11 data types

used as it is the stable IFC platform till the end of the year 2005. The Schema contains the entity definitions like a package that contains classes in an object oriented programming language, e.g. Java.

- **Entity Definitions** — Entity definitions describe classes of real-world objects with associated properties. The properties are called attributes and can be simple values, such as a “name” or a “weight,” or relationships between instances, such as “owner” or “part of”. Entities inherit attributes from super-types. The inheritance model supports single and multiple inheritance, as well as a new type, called AND/OR inheritance which is not used in the IFC EXPRESS definition schema and thus, not discussed in the scope of this work. e.g.:

```
Entity Date;
      year : INTEGER;
      month: INTEGER;
      day  : INTEGER;
End_Entity;
```

In other words, 'Entity' data type is a class that establishes a domain of values defined by common attributes and constraints (local rules). The 'Entity' may contain the

following declarations in the following sequence (supertype declarations, subtype decelerations, explicit attributes, derived attributes (DERIVED), inverse attributes (INVERSE), uniqueness rules (UNIQUE), and local rules(WHERE)).

- **Type Definitions** — Type definitions describe ranges of possible values. The language provides several built-in types, and the modeler can construct new types using the built-in types, generalizations of several types, and aggregates of values. e.g.:

```
TYPE month = ENUMERATION OF(January,February,March,
April,May, June, July, August,September, October,
November,December);
END_TYPE;
ENTITY date;
Month_component : Month;
END_ENTITY;
```

The TYPE deceleration creates a new 'defined type' based on an 'underlying type'. It is mainly used to increase the semantics of the underlying type through constraining the type, usually by using local (WHERE) rules e.g. :

```
TYPE label = STRING;    END_TYPE;
TYPE age= INTEGER;
WHERE SELF >= 0;        -- "self" corresponds to "this" in Java
END_TYPE;
```

There are two main constrained types of the EXPRESS type. The first is the SELECT data type. Its domain consists of the union of named data types in its select list. It is used as a sort of generalization of dissimilar types. e.g.:

```
TYPE Circle_dim =SELECT (Radius, Diameter);   END_TYPE;
TYPE Radius= SELECT (Inch, Meter);            END_TYPE;
TYPE Diameter= SELECT (Inch, Meter);          END_TYPE;
TYPE Inch =REAL;                              END_TYPE;
TYPE Meter = REAL;                            END_TYPE;
```

The second type is the ENUMERATION data type. It defines an ordered set of named values (enumeration items) e.g.:

```
TYPE month =ENUMURATION OF (
January, February, March, April, May, June, July, August,
September, October, November, December);
END_TYPE;
ENTITY date;
       Month_Component: Month;
```

```
END_Entity;
```

- **Correctness Rules** — A crucial component of entity and type definitions are local correctness rules. These local rules constrain relationships between entity instances or define the range of values allowed for a defined type. Global rules can also make statements about an entire information base. Moreover, each rule is assigned a name.
e.g.:

```
Entity Date;
year : INTEGER;
month: INTEGER;
day  : INTEGER;
WHERE
ad: year> 0;              -- "ad" is the name of the rule.
End_Entity;
```

- **Algorithmic Definitions** — An information modeler may also define functions and procedures to assist in the algorithmic description of constraints.

e.g.:

```
Acos (0.3) ---> 1.266
Asin (0.3) ---> 3.0469
Sin (pi)   ---> 0.0
```

- **Simple Data Types:** Figure 5.25 shows the EXPRESS data types. The simple data types define the atomic data units. They can not be further divided into elements that EXPRESS can recognize. Number is an abstract data type for all numeric values. REAL represents all rational, irrational and scientific real numbers. INTEGER represents all integer numbers. INTEGER and REAL are both specializations of Number. Moreover, INTEGER is a specialization of REAL. STRING represents sequences of characters defined by ISO 10646.

- **Container Classes (Collections)**—Aggregation data types have a domain of values of a given data type called elements of the aggregate collection. The ARRAY data type has an indexed domain with a fixed size collection of like elements. It may use the optional UNIQUE to specify that an array can not contain duplicate elements. It may also use negative integers in its index, the last line in the following code extract declares an array that contains a hundred element of the entity *Person*. The

OPTIONAL keyword indicates that the elements of the array can reference either a *Person* entity or null **e.g. :**

```
- ARRAY [1:10] OF INTEGER
- ARRAY [-10:100] OF UNIQUE (STRING)
- ARRAY [1:100] OF OPTIONAL PERSON
```

The LIST data type has a sequence of like elements as its domain (with a variable size). It may also use the optional UNIQUE to specify that a list can not contain duplicate elements. e.g.:

```
- LIST [1:?] OF REAL
- LIST OF UNIQUE PRODUCT
```

The ARRAY and LIST are both ordered aggregates. On the other hand the EXPRESS language supports two unordered aggregate types; BAG and SET. The BAG data type has a variable size domain that consists of like elements in which duplication is allowed. e.g.:

```
- BAG [1:100] OF NUMBER
- BAG OF ELEMENT
```

The SET data type has a variable size domain that contains an unordered collection of like elements in which no two elements can have instance equality. e.g.:

```
- SET [1:10] OF STRING (10) FIXED
- SET OF PERSON
```

Finally, there are nested aggregates that contain aggregates themselves. e.g.:

```
- ARRAY [1:10] OF LIST OF DOCUMENT
- LIST OF SET OF ARRAY [-10:10] OF INTEGER
```

It should also be mentioned that a LIST OF UNIQUE item is a specialization of LIST of item. ARRAY OF UNIQUE item is a specialization of ARRAY OF ITEM. ARRAY OF item is a specialization of ARRAY OF OPTIONAL item and finally a SET OF item is a specialization of BAG OF item.

In Java, on the other hand, the List class as well as the other container classes (e.g. Set) can contain elements of any type as long as they are derived from the super class object. From the above mentioned explanation; we can notice the differences between Java and EXPRESS in imposing constraints on container classes.

5.5.2.2 STEP Standard Data Access Interface (SDAI)

A first step in mapping EXPRESS entities to Java classes is building an SDAI (Standard Data Access Interface). The SDAI is a STEP API for EXPRESS defined data. The SDAI protocols contain a description of the operations and functionalities that should be satisfied by the mapped entities. The SDAI is described by several ISO standards documents. STEP Part 22 (ISO 10303-P21 1995) contains a functional description of the SDAI operations, while Parts 23 (ISO 10303-P23 1995) and 24 (ISO 10303 P-24 1995) describe how these operations are made available in the C++ and C language environments. Bindings for CORBA/IDL and Java are also available. As a general rule, all mapped EXPRESS entities should implement the SDAI interface. The only purpose of this interface is the definition of rules that the generated Java classes must implement to get access to their inner attributes (Loffredo, 2004). There are two main types of bindings available:

- **SDAI Late Binding —** In this approach, no pre-generated data structures are used. Only one data structure is used for all of the definitions in an EXPRESS model. The Inner attributes are usually collected in a container class, e.g. Vector or List. Moreover, access to the objects is provided at runtime (ibid).

- **SDAI Early Binding —** An early binding approach makes the EXPRESS information model available as specific programming language data structures for each different definition in the EXPRESS model i.e. a dictionary (Schwarz 2004). For example, an early binding such as the SDAI Java would contain specific Java classes for each definition in the IFC2x Schema. One major advantage to this

approach is that the compiler can do extensive type checking on the application, detecting conflicts at compile time. Special semantics or operations can also be captured as operations tied to a particular data structure. Early bindings are usually produced by an EXPRESS compiler. The compiler will parse, resolve, and check the EXPRESS model, then passes control to a code generator to produce data structures for that model. EXPRESS entity definitions are usually converted to Java or C++ classes where type definitions are converted to either classes or typedefs, and the EXPRESS inheritance structure is mapped into Java / C++ classes. Each class should have access and update methods for the stored attributes, possibly access methods for simple, derived attributes, and constructors to initialize new instances. It should be also noticed that Java does not support multiple inheritance. At any rate, this problem is not encountered in this work due to the fact the the EXPRESS definition of the IFC model does not use any direct multiple inheritance.

- **Other Approaches —** The early and late bindings are not the only possible approaches. In the scope of this work a mixed approach is implemented. This approach provides the advantages of an early binding (compile-time type checking) without the complexity introduced by modelling a huge number of classes in the IFC model (there are more than three hundred and seventy leaf classes, in addition to eighty nine defined types, twenty three select types and one hundred and seventeen enumerations). It should be mentioned that in the the early binding approach there is a restriction to predefined classes. This means that if we need to interpret Ifc2x compliant STEP files, we have to model all the elements of the IFC2x model to Java classes. In the meantime, if we need to change to IFC2x2, then we have to do the same again with the whole model to produce new Java binding classes. A mixed binding takes advantage of the observation that applications rarely use all of the structures defined by the IFC2x

EXPRESS Schema. The subset of structures that are used, called the *working set,* can be early-bound, while the rest of the Schema is late-bound (idem 2004). Therefore, all data is still available, but the application development process is simplified. The number of classes and files that are needed is reduced dramatically, resulting in quicker compiles, simpler source control, and more rapid development.

In the scope of this work the mixed approach was implemented, in the early binding parts (for *working classes*) a more labour-intensive approach has been used to hand-generate an early binding for the IFC2x model. Such a binding is not 100% compliant to the IFC EXPRESS model, due to the fact that EXPRESS data types can not be mapped 1:1 to Java data types. In addition to the strong constraints and rules that are imposed by the EXPRESS language.

Although this approach might provide a simplified programming interface, there are some drawbacks to be aware of. Aside from the increased labour involved in defining and implementing the binding, this method requires that the user should understand the EXPRESS schema API completely, and be able to predict how it will be used (Loffredo 2004).

5.5.2.3 Mapping EXPRESS Data Types

This section describes how EXPRESS language data types are mapped to the Java language through the exchange structure (STEP physical file). The EXPRESS language includes TYPE and ENTITY declarations, CONSTANT declarations, constraint specifications and algorithm descriptions. Only EXPRESS primitive data types, TYPE, ENTITY and aggregations declarations, are mapped to the exchange structure. Other elements of the language are not mapped to the exchange structure and consequently are not mapped to Java classes. Table 5.3 shows the

mapping from EXPRESS to STEP and Java types. The first two columns in the table are taken from the ISO 10303-21:1994/Cor.1:1995/DAM 1 specifications while the third column is developed by the author.

The following is an explanation of the mapping between types that can not be mapped 1:1 from EXPRESS to Java according to the mappings in table 5.3.

EXPRESS element	**Mapping to STEP-P21:**	**Mapping to Java**
ARRAY	list	List
BAG	list	List
BOOLEAN	boolean	See below
BINARY	binary	binary
CONSTANT	NO INSTANTIATION	NO INSTANTIATION
DERIVED ATTRIBUTE	NO INSTANTIATION	NO INSTANTIATION
ENTITY	entity instance	Class
ENTITY AS ATTRIBUTE	entity instance name	Reference to object
ENUMERATION	enumeration	(Class) See below
FUNCTION	NO INSTANTIATION	NO INSTANTIATION
INTEGER	integer	integer
INVERSE	NO INSTANTIATION	NO INSTANTIATION
LIST	list	List
LOGICAL	enumeration	Class (see below)
NUMBER	real	double
PROCEDURE	NO INSTANTIATION	NO INSTANTIATION
REAL	real	double
REMARKS	NO INSTANTIATION	NO INSTANTIATION
RULE	NO INSTANTIATION	NO INSTANTIATION
SCHEMA	NO INSTANTIATION	Package (in early binding)
SELECT	See below	See below
SET	list	List
STRING	String	String
TYPE	See below	Class (See below)
UNIQUE rule	NO INSTANTIATION	NO INSTANTIATION
WHERE RULES	NO INSTANTIATION	NO INSTANTIATION

Table 5.3 Mapping EXPRESS to STEP & Java, (Nour et al 2005)

Logical & Boolean Values — Values of the EXPRESS data type LOGICAL are mapped to the exchange structure (STEP file) as an enumeration data type. It is treated as a predefined

enumerated data type with a value encoded by the characters "T", "F" or "U". These values correspond to true, false, and unknown respectively. Whereas the boolean data types are mapped to “T” or “F” for true and false respectively . BOOLEAN is considered to be a specialization of LOGICAL. The following code cut out from a STEP P-21 file, shows how boolean attributes are mapped in a STEP model.

```
#795 = IFCPROPERTYSINGLEVALUE ('IsExterior', $, IFCBOOLEAN (.T.), $);
```

“IFCBOOLEAN (.T.)” means that the boolean attribute of this EXPRESS entity has the value *“true”*. Boolean and Logical data types are mapped to Java in the same manner as enumerations. This is discussed in detail in the enumerations section below.

Enumeration data type— In general, the actual value of an enumeration is one of a predefined enumerated values in the EXPRESS schema (e.g. red, green and blue in the following code cut-out). In the STEP file, any small letters shall be converted to the corresponding capital letters, and the value shall be delimited by full stops "." . e.g.:

```
-- EXPRESS definition
TYPE
primary_colour = ENUMURATION OF (red, green, blue);
END_TYPE
ENTITY widget;
p_colour : primary_colour; ------------> A
END_ENTITY;
-- Mapping to STEP-P21 file
#2= WIDGET (.RED.);
              ^
              A
```

In Java an Enumeration is a kind of a deprecated *Iterator* interface. It is mainly used to iterate over the elements of a collection (e.g. Vector). Thus, it has nothing to do with the EXPRESS Enumeration. Consequently, the mapping to Java had to bear in mind and try to model the EXPRESS definition and use of the Enumeration type. The following is a code cut out that shows an example of the mapping from the IFC model:

```
package step_parser.util;
public interface Enum {
      public String getSelection();
      public void setSelection(String sel);
      public void setSelection (int sel);
```

```
      public int getSelectionOrder (); }
```

The previous interface is implemented by all Enumeration types in the mapped EXPRESS definition of the IFC2x model in the early binding approach. They are one hundred and seventeen classes that have the "IFCxxxxxEnum" naming convention. As it can be seen from the following code extract, the enumerations include an ordered set of named values, e.g. the months of the year, the operation style of a door or a window, or the materials relative to a certain construction product and so forth. Each choice corresponds to an integer value that corresponds to its order. The Java mapping establishes a Hash Map between integer values (the order) and the named values in a manner that enables mapping them to each other. The mapping performs a check that either the given string value or the integer value in the *set* methods are valid during the interpretation process from the parsed STEP model at run time. Once a value or its order is already set. The value or the order can then be retrieved whenever needed by the *get* methods.

```
package IfcModel.IfcSharedBldgElements;
public class IfcDoorStyleOperationEnum implements Serializable , Enum {
      private HashMap m;
      public static final int
      SINGLE_SWING_LEFT=0,
      SINGLE_SWING_RIGHT=1,
      DOUBLE_DOOR_SINGLE_SWING=2,
      DOUBLE_DOOR_SINGLE_SWING_OPPOSITE_LEFT=3,
      DOUBLE_DOOR_SINGLE_SWING_OPPOSITE_RIGHT=4,
      DOUBLE_SWING_LEFT=5,
      DOUBLE_SWING_RIGHT=6,
      DOUBLE_DOOR_DOUBLE_SWING=7,
      SLIDING_TO_LEFT=8,
      SLIDING_TO_RIGHT=9,
      DOUBLE_DOOR_SLIDING=10,
      FOLDING_TO_LEFT=11,
      FOLDING_TO_RIGHT=12,
      DOUBLE_DOOR_FOLDING=13,
      REVOLVING=14,
      ROLLINGUP=15,
      USERDEFINED=16,
      NOTDEFINED =17;
      public static final String[] values ={
      ".SINGLE_SWING_LEFT.",".SINGLE_SWING_RIGHT.",
      ".DOUBLE_DOOR_SINGLE_SWING.",
      ".DOUBLE_DOOR_SINGLE_SWING_OPPOSITE_LEFT.",
      ".DOUBLE_DOOR_SINGLE_SWING_OPPOSITE_RIGHT.",
      ".DOUBLE_SWING_LEFT.",
      ".DOUBLE_SWING_RIGHT.", ".DOUBLE_DOOR_DOUBLE_SWING.",
      ".SLIDING_TO_LEFT.", ".SLIDING_TO_RIGHT.",    ".DOUBLE_DOOR_SLIDING.",
      ".FOLDING_TO_LEFT.", ".FOLDING_TO_RIGHT.",    ".DOUBLE_DOOR_FOLDING.",
      ".REVOLVING.", ".ROLLINGUP.", ".USERDEFINED.", ".NOTDEFINED."};
      private int value;
      public IfcDoorStyleOperationEnum (Object type){
            String a= type.toString();
```

```
            m = new HashMap();
            for (int i=0; i< values.length; i++)
            {
                  m.put((Object)values[i], ((Object)new Integer (i)));
            }
            value=  Integer.parseInt( (m.get(a).toString()));
      }
      public IfcDoorStyleOperationEnum (int enum){
            if (enum >= 0 && enum <= values.length)
            value=enum;
            else
            //("An Exception has to be thrown / out of Enumeration Bounds");
      }
      public String getSelection(){
            return values[value];
      }
      public int getSelectionOrder(){
            return this.value
      }
      public void setSelection(String sel){
            for (int i=0; i < values.length; i++)
            {
                  if (values[i].compareTo(sel)==0)// check if the value is valid ?
                  value=i;
                  else
                  //("An Exception is thrown");
            }
      }
      public void setSelection (int sel){
            if (sel >=0 && sel <= values.length)// check if order is in range ?
            value=sel;
      }
}
```

Figures 5.26 , 5.27 and the above code extracts show together how the enumerations in STEP-P21 model are interpreted to Java early bindings. First the order of the possible values of the enumeration is defined as integers constants. Second, the values are included in a constant array of Strings according to the order defined in the first stage. Finally, the *set* and *get* methods provide the earlier explained functionalities of the *Enum* interface, in addition to the required validity checks.

Figure 5.26 shows a UML diagram that represents the above Java code, where the IfcDoorStyle has references to two enumerations that implement the interface *"Enum"* according to the above mentioned explanations. Figure 5.27 represents an EXPRESS-G diagram that shows the corresponding EXPRESS definition for the above example.

```
EXPRESS ISO 10303-P11 definition of "IfcDoorStyle" entity
ENTITY IfcDoorStyle
      SUBTYPE OF (IfcTypeProduct);
```

```
      OperationType      :   IfcDoorStyleOperationEnum;
      ConstructionType   :   IfcDoorStyleConstructionEnum;
      ParameterTakesPrecedence   :   BOOLEAN;
      Sizeable   :   BOOLEAN;
END_ENTITY;
An extract from a STEP-P21 file that shows the mapping from EXPRESS to STEP
#9015 = IFCDOORSTYLE
('OIP_01d2754ae',#195,$,$,$,$,$,$,.SINGLE_SWING_RIGHT.,.ALUMINIUM.,.F.,.F.);
                                    ^                    ^
                    IfcDoorStyleOperationEnum        IfcDoorStyleConstructionEnum
```

The above code cut out shows the mapping from EXPRESS to the STEP-P21 file for the enumeration *IfcDoorStyleOperationEnum*, which is an attribute of IfcDoorStyle The enumeration is defined as a *single_swing_right* instance. The reader has to imagine that the above STEP code is parsed and a new instance of the class is instantiated at run-time using the parameters provided in the STEP entity, by the interpreter. Accordingly, the value of the enumeration has to be defined at run-time using one of the *set* methods.

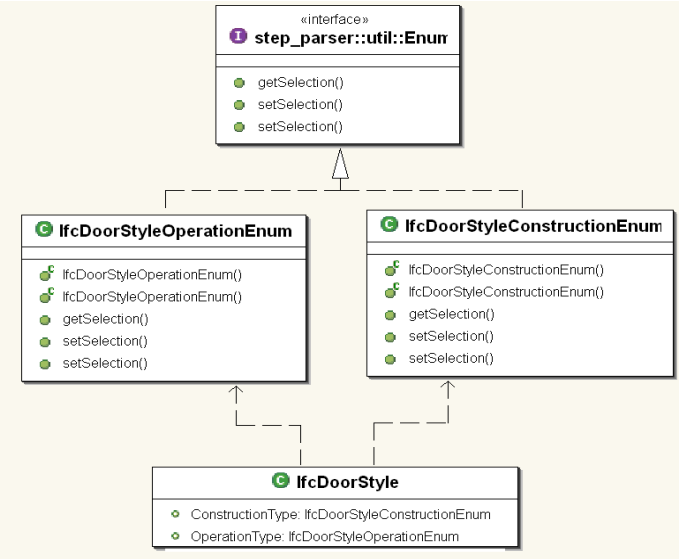


Figure 5.26 A UML diagram for Mapping IFC Enumerations to Java

By following the above example, code cut outs, figures 5.26 and 5.27 and the EXPRESS definition of the entity *IfcDoorStyleOperationEnum* from the IAI documentation, the reader can have a good grasp of the mapping process from EXPRESS P-11 Enumeration data type to Java through STEP P-21.

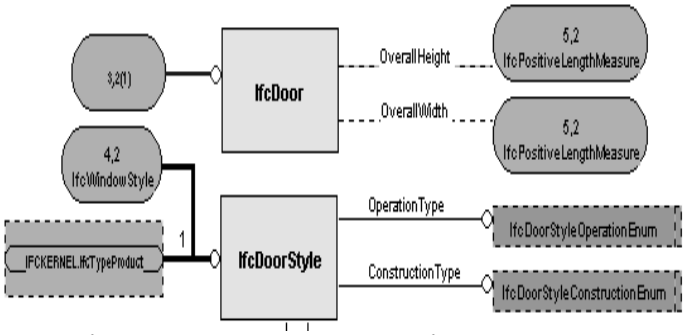


Figure 5.27 An EXPRESS-G diagram for the enumerations, IFC2x Model Implementation Guide (2002)

Select data type— An EXPRESS select data type defines a list of data types, called the *"select-list"*, whose

values are valid instances of the select data type. An instance can be at least one of the types in the select-list. Generally speaking, in the STEP file, small letters are converted to capital letters, i.e. the encoding does not contain any small letters. e.g.:

```
ENTITY Employee;
      name: String;
END_ENTITY;

ENTITY Leader SUBTYPE OF (EMPLOYEE);
      project: STRING;
END_ENTITY;

ENTITY Manager SUBTYPE OF (EMPLOYEE);
      unit: STRING;
END_ENTITY;

TYPE Supervisor = SELECT (Manager, Leader);
END_TYPE;

ENTITY Meeting;
      date: STRING;
      attendees: SET [2:?] OF Supervisor;
END_ENTITY;

-- Instantiated in STEP-P21 as:
#1 = LEADER ('J.Brahms', Academic Festival');
#2 = MANAGER ('S. Ozawa', 'Tokyo Symphony');
#3 = EMPLOYEE ('Martin');
#4 = MEETING ('14921012', (#1, #2));
                  ^          ^
               1-date    2-attendees (set of Supervisors)
```

We can see from the above EXPRESS and STEP code that the second attribute of #4 is the attendees: a SET OF Supervisor (minimum two). Instances #1 and #2 are a Leader and a Manager and thus are considered to be valid Supervisors. On the other hand, #3 is an is not of type *"Supervisor"* and therefore, can not be a member of a *"Meeting"*.

The following code shows an example of the EXPRESS definition of a select data type from the IFC2x model. The IfcMaterialSelect is a type that contains three different and mutually exclusive entities (material, material list and material layer set usage). The first represents a simple material, the second is a list of simple materials, the third is a list of materials in a layering system, where a connection with the geometry of the construction product plays an important role.

```
-- EXPRESS definition of IfcMaterialSelect Type
TYPE IfcMaterialSelect = SELECT
 (    IfcMaterial,
```

```
      IfcMaterialList,
      IfcMaterialLayerSetUsage);
END_TYPE;
```

The IFC2x model contains twenty three select data types that are mapped to early binding Java classes by using the interface '*Select*'. The following code cut-out shows the interface and how it is able to get the underlying type object at run-time (whether it is a simple material, material list or materiallayersetusage and so forth) together with the implementation in the class IfcMaterial.

```
package step_parser.util;
public interface Select {
      public String Underlying_typeName();
      public Object Underlying_typeObject();
}
-----------------------------------------------------------------------
public class IfcMaterial implements IfcMaterialSelect, Serializable{
   public String Name= null;
   public transient ArrayList ClassifiedAs=null;  // INVERSE attribute
   public IfcMaterial(){}
   public String Underlying_typeName() {
      return ((Class)this.getClass()).getName();
   }
   public Object Underlying_typeObject() {
      return this;
   }
}
```

The above code represents just a simple example that shows the reader the mapping to Java. During the interpretation of the parsed STEP file, the interpreter needs to get hold of the type of instance of the the object that has been delivered by the parser. By using the methods provided by the *Select* interface (Underlying_typeName and Underlying_typeObject), the interpreter can create a new instance of the correct type at run time. Furthermore, it can perform a type checking before casting the newly created object at runtime to its class.

```
EXPRESS definition of IfcRelAssociatesMaterial
ENTITY IfcRelAssociates;
      RelatedObjects   :   SET [1:?] OF IfcRoot;
END_ENTITY
ENTITY IfcRelAssociatesMaterial; SUBTYPE OF (IfcRelAssociates)
      RelatingMaterial   :   IfcMaterialSelect;
END_ENTITY;
```

By looking at the above EXPRESS definition of the IfcRelAssociatesMaterial entity and its supertype (IfcRelAssociates), it can be noticed that it links a set of one or more objects in the IfcModel through their *IfcRoot* superclass and a material through the attribute *"RelatingMaterial"* which references an *IfcMaterialSelect* type. This select type can be an

IfcMaterial, an IfcMaterialList or an IfcMaterialLayerSetUsage. This has to be determined at runtime by the interpreter using the functionalities of the *Select* interface.

After describing the mapping between EXPRESS, STEP and Java types, the following section will describe the process of interpreting the parsed STEP file to IFC2x Java Classes. Before doing this, it is worth looking at an extract of a simple IFC2x/STEP file describing an IFCWALLSTANDARDCASE entity, together with the EXPRESS definition of the wall. In the scope of this work it is of paramount importance to fully understand the IFC2x model and make sure that the interpretation is complainant and consistent with the original EXPRESS definition.

```
ENTITY IfcWallStandardCase;
ENTITY IfcRoot;
      GlobalId            :   IfcGloballyUniqueId;
      OwnerHistory        :   IfcOwnerHistory;
      Name                :   OPTIONAL IfcLabel;
      Description         :   OPTIONAL IfcText;
ENTITY IfcObject;
      ObjectType          :   OPTIONAL IfcLabel;
      INVERSE
      IsDefinedBy         :   SET OF IfcRelDefines FOR RelatedObjects;
      HasAssociations     :   SET OF IfcRelAssociates FOR RelatedObjects;
      HasAssignments      :   SET OF IfcRelAssigns FOR RelatedObjects;
      Decomposes          :   SET OF IfcRelDecomposes FOR RelatedObjects;
      IsDecomposedBy      :   SET [0:1] OF IfcRelDecomposes FOR
                              RelatingObject;
ENTITY IfcProduct;
      ObjectPlacement     :   OPTIONAL IfcObjectPlacement;
      Representation      :   OPTIONAL IfcProductRepresentation;
      INVERSE
      ReferencedBy        :   SET OF IfcRelAssignsToProduct FOR
                              RelatingProduct;
ENTITY IfcElement;
      Tag                 :   OPTIONAL IfcIdentifier;
      INVERSE
      ConnectedTo         :   SET OF IfcRelConnectsElements FOR
                              RelatingElement;
      ConnectedFrom       :   SET OF IfcRelConnectsElements FOR
                               RelatedElement;
      ContainedInStructure:   SET [0:1] OF
                              IfcRelContainedInSpatialStructure FOR
                              RelatedElements;
ENTITY IfcBuildingElement;
      INVERSE
      ProvidesBoundaries  :    SET OF IfcRelSpaceBoundary FOR
                               RelatedBuildingElement;
      HasOpenings         :    SET OF IfcRelVoidsElement FOR
                               RelatingBuildingElement;
      FillsVoids          :    SET OF IfcRelFillsElement FOR
                               RelatedBuildingElement;
END_ENTITY;
```

```
-- MAPPING to STEP-P21 (a code cut out from a STEP file):
#57 = IFCWALLSTANDARDCASE ('1juGXWoCL1auasdHNXsRHo', #6, 'Wand-
      006', $, $, #56, #54, $);
```

Both the above EXPRESS code and the UML diagram in figure 5.28 show the inheritance tree of the *IFCWALLSTANDARDCASE* entity. It is inherited from *IfcWall* but with further restrictions that are imposed by the EXPRESS *WHERE* rules. *IfcRoot* is the upper most abstract entity in the IFC Model where all entities are rooted. It can be resembled to the class *"Object"* in the Java programming language. *"An IfcObject is the generalization of any semantically treated thing or process within IFC"*. IfcProduct is *" Any object, manufactured, supplied or created for incorporation into an AEC/FM project"*. IfcElement is *"A Generalization of all components that make up an AEC product"*. IfcBuildingElement *"comprises all elements that are primarily part of the construction of a building, i.e., its structural and space separating system."* e.g. building elements like walls, beams, or doors, they are all physically existent and tangible things. (IAI) At the bottom end of the of the above EXPRESS code, there is the STEP mapping of the entity. It begins with the numerical identifier (#57 =) then the entity's name followed by a list of attributes that are arranged in superclass-to-subclass order between parenthesis. The first attribute is the GUID (Global Unique Identifier) of the Instance. The second attribute is a reference to the *IfcOwnerHistorey*. The third attribute is the name of the wall ('wand-006', an optional attribute). The fourth attribute is an optional description that is undefined, thus written in STEP as a "$". These four attributes are defined in the IfcRoot super-

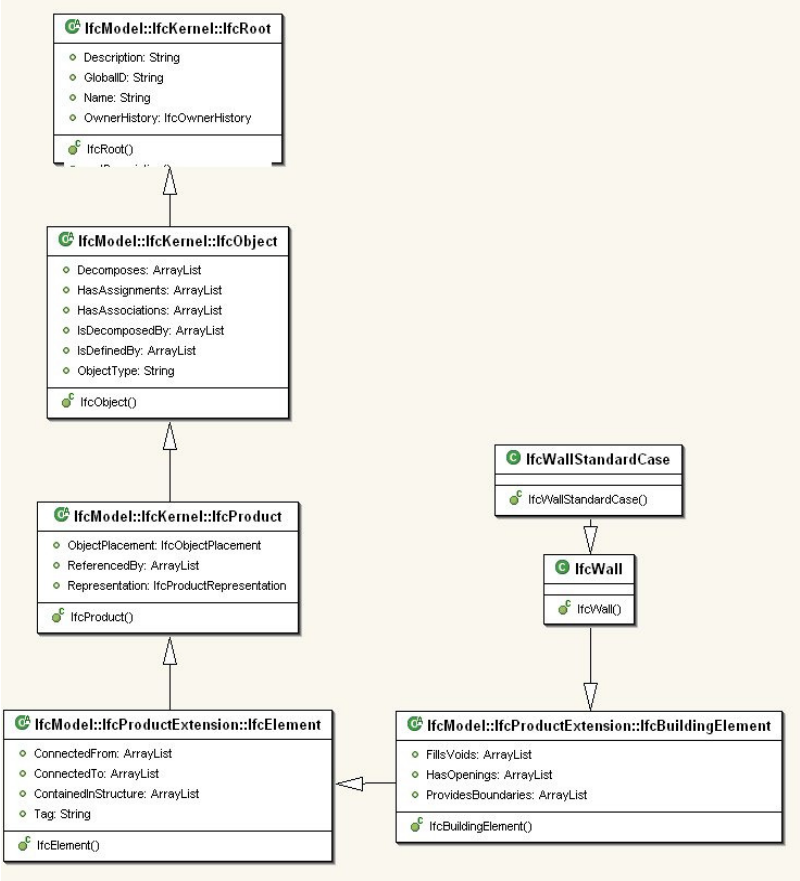


Figure 5.28 A UML diagram showing the inheritance tree of an IfcWallStandardCase

type. The fifth attribute is an optional label attribute that belongs to the IfcObject supertype and is undefined and written as a "$". #56 and #54 are references to the positioning and graphical representation of the wall respectively. They are the two attributes of the superclass IfcProduct, where each product in the IFC model should have a location in the coordinate space and at least one geometrical representation. These issues will be discussed later in this work in detail in the visualization section.

By looking at both the previous EXPRESS code and the STEP mapping. The following observations can be noticed:

1- The optional attributes of the EXPRESS language may and may not be instantiated in the STEP physical file. If they are not, they are represented by the '$' symbol, which in turn has to be translated to a null reference in Java.

2- Both the Inverse and the Derived attributes are not mapped to the STEP file. (similar to transient and static attributes in Java). It should also be noticed that the IFC model relies very heavily on the Inverse attributes in creating references between objects and the relations in the IfcKernel and their sub-types. Hence alternative means of reaching the attributes has to be established to be able to conduct any queries in the model.

3- The references between objects are established through IDs that are represented by a numerical identifier preceded by a '#'.

4- Container classes (Sets, List, Arrays and Bags) are represented by arguments that are nested between extra parenthesis.

By analyzing the STEP/IFC code in appendix A1, we can see how the file describes the wall. IFC files usually begin with defining the measuring units as seen in section 1 of the code. Section 2 shows the definition of the materials that are later related to the wall. Section 3 shows the relations that join the project constituents together (aggregation relations) as shown in figure 5.37; Project to Sites, each site to its Buildings, each Building to its Building Stories and each

Building Story to its constituents (Products).

5.5.2.4 IFC2x Interpreter

After parsing the STEP file, the IFC model is obtained in the form of a three dimensional array, as earlier explained. The following algorithm describes the process of interpreting the parsed code to IFC2x Java classes, where a mixed early and late binding approaches are used together. The author did not build an EXPRESS compiler that automatically generates the Java classes as a result of the mapping between EXPRESS entities and Java classes but depended on a good understanding of the IFC2x model in manually creating the mapping.

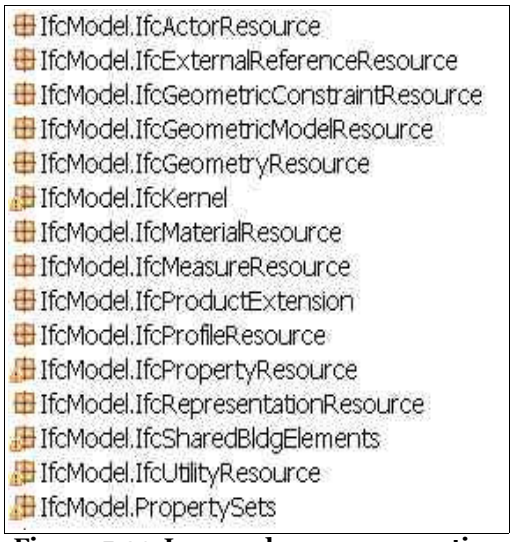


Figure 5.29 Java packages representing IFC EXPRESS schemata

Step One — is the building of Java classes that are mapped from the IFC2x EXPRESS entities i.e. an early binding approach. This was done for about more than seventy seven working classes and more than three hundred and twenty abstract and super classes. This shows that it is possible to work with a subset of the entire IFC model entities using an early binding approach, whereas the rest can be used as late binding classes at runtime. Each IFC EXPRESS Schema is mapped to a Java package as shown in figure 5.29 and each mapped class implements the SDAI interface that provides the functionalities that insure reaching the inner attributes of the class. The following code extract shows the SDAI interface's method that provide access to the newly generated IFC2x Java classes.

```
package step_parser.util;
public interface SDAI {
      public String getName();  // returns the name of the class.
      public String getLnNr (); // returns the identifier
      public void setLineNr (long lnr);  // sets a new identifier
      public Object[] getAttributes();   // returns the attributes
      public Object getIfcCmp ();  // returns the IFC Component
      public void setAttributes (Object[] att);  //sets Attributes }
```

In the early binding approach the EXPRESS entities are mapped to Java classes with no implementation, only as attributes. The implementation is then determined by a subclass that takes the name of the superclass preceded by a "_" as shown in the UML diagram in figure 5.30. The following code shows an example of an IfcDoor EXPRESS entity that is mapped to an IfcDoor Java Class. It is noticed that there is no implementation methods in the class and all of the implementation is transferred to the subclass _ifcdoor. This is done intentionally to keep the Java Ifc2x model pure and away from the influence of any implementation. This is envisaged to enable other users to use the model and provide their own implementation without any limitation to the author's use of the model.

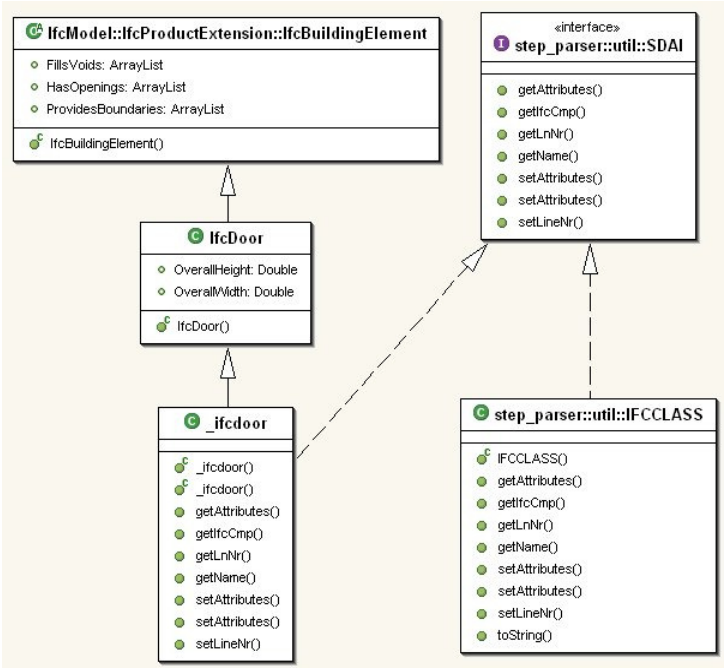


Figure 5.30UML diagram showing the separation between the IFC model and its implementation, (Nour et al, 2005)

```
package IfcModel.IfcSharedBldgElements;
public class IfcDoor extends IfcBuildingElement implements Serializable{
   public Double OverallHeight=null;
   public Double OverallWidth=null;
   public IfcDoor() {
      super();
   }
}
```

The above code shows the class IfcDoor while the following code shows the implementation class _ifcdoor:

```
package IfcModel.IfcSharedBldgElements;   // early binding example
public class _ifcdoor extends IfcDoor implements SDAI, Serializable {
      private Object[] arguments;
      private String ln_nr=null;
      public _ifcdoor(Object[] att){
         this.arguments= att;
         this.ln_nr=att[0].toString();
      }
      public _ifcdoor(){
               super();
      }
```

```
	public String getName(){
		return arguments[1].toString();
	}
	public String getLnNr (){
	   return this.ln_nr;
	}
	public Object[] getAttributes(){
		return this.arguments;
	}
	public void setAttributes(Object[] my_att)
	{
		if (my_att != null){
		this.arguments=my_att;
		this.ln_nr=my_att[0].toString();
		super.GlobalID= (String)this.arguments[2];
		super.OwnerHistory= (IfcOwnerHistory)this.arguments[3];
		super.Name=arguments[4]==null ? null : (String)
		this.arguments[4];  // handling optional attributes
		super.Description= arguments[5]== null ? null : (String)
		this.arguments[5]; // OPTIONAL ATTRIBUTES
		super.ObjectType= arguments[6]== null ? null : (String)
		this.arguments[6];
		super.ObjectPlacement=(IfcObjectPlacement)arguments[7];
		super.Representation=(IfcProductRepresentation)arguments[8];
		super.Tag=((String)arguments[9])==null ? null :
		(String)this.arguments[9];
		super.OverallHeight=arguments[10]==null ? null : new Double
		(this.arguments[10].toString());
		super.OverallWidth= arguments[11]==null ? null : new Double
		(this.arguments[11].toString());
		}
	}


	public Object getIfcCmp(){
	   return this.ifc;
	}
	public void setLineNr(long lnr) {
	   this.ln_nr="#"+lnr;
	   this.arguments[0]="#"+lnr;
	}
}
```

Type Checking of the attributes for the Early Binding.

The following is an explanation to the implementation of the SDAI interface. It is important here to remind the reader that the main aim behind this interface – as earlier discussed in detail - is making the attributes of the EXPRESS entity available to the software application. The getLnNr() method returns back the line number identifier of the entity. The SetLineNr method sets a new line number identifier for the STEP entity (e.g. #xxx). This method is used when exporting the IFC2x model in the form of a STEP file.(when traversing the whole IFC model's tree structure in a post order recurring manner, as it is explained later in section 5.5.4.4). The getAttributes method returns the attributes' values of the STEP mapping of the EXPRESS entity in the form of an array. The first element of this array is always the line number identifier. The second element is the name of the EXPRESS entity (IFCxxx). The rest of the elements represent the arguments of the

EXPRESS entity that are mapped to the STEP model and obtained from the parser. The *getIfcCmp* method returns the IFC component object that has no implementation, i.e. The super type of the implementation class. However, its attributes are public and thus, can be reached directly. Finally, the *setAttributes* method takes an array that represents the arguments of the EXPRESS entity that are mapped to the STEP model as its input parameter.

We can see from the above code extract how the early binding approach performs a type checking in the *setAttributes* method. Whenever there is a mistake a Java class cast exception is thrown. We can also notice that null values are instantiated in cases where the EXPRESS OPTIONAL attributes are not assigned to any values i.e. "$". e.g. the attributes Name, Description and Tag in the entity IfcDoor's superclasses, as shown in the previous code.

In the late binding approach, one class is used for all EXPRESS entities (step_parser.util.IFCCLASS in appendix C). This class contains an attribute that is an array that contains all the arguments of the EXPRESS entity. The following code extract shows the structure of this class where the difference between it and the early binding approach can be clearly noticed in the *setAttributes* method. This approach does not perform any attribute type checking. The array of arguments is kept as it is and its elements are not casted to any predefined classes.

```
package step_parser.util;
//    Late Binding Implementation
public class IFCCLASS implements SDAI
{
      private Object[] arguments= null;
      private String class_name= null;
      private String ln_nr=null;             // id
      public IFCCLASS(){
      }
      // the SDAI interface implementation
      public void setAttributes (Object[] param){
             if (param != null){
                   this.arguments =param;
                   this.class_name = (String) this.arguments[1];
                   this.ln_nr = (String) this.arguments [0]; // id
             }
      }
      public Object[] getAttributes(){
            return arguments;
      }
      public String getName(){
            return this.class_name;
      }
      public String getLnNr(){
```

```
            return this.ln_nr;
      }
      public Object getIfcCmp (){
            return null;        // because it is a late binding
      }
      public void setLineNr(long lnr){ // needed later, when writing STEP
            this.ln_nr="#"+lnr;
            this.arguments[0]="#"+lnr;
      }
}
```

Before proceeding to Step two of the interpreting algorithm we should have another look at the entire STEP file in appendix A1. The following facts can be noticed:

1- The identifiers (line numbers) are nearly arranged in an ascending order to a great extent. However, this is not a strict rule, many exceptions could still be found e.g. the element #28 comes after the element #75 and so forth (as seen in the STEP file in appendix A1). Moreover, it should be noticed that an IFC element with an identifier #x does not have an attribute that references another element with an identifier #y, where (y > x) e.g.

```
 #49 = IFCEXTRUDEDAREASOLID (#47, #48, #22, 2.7);
```

we can see that #49 has references to #47, #48 and #22, where they are all smaller than 49. Again this was found not to be a strict rule and that there are some rare exceptions to this rule e.g.

```
#26 = IFCPROJECT ('2CG4MunUj4vO3nI3z9Vhqx', #6, 'Default Project', $, $, $, $,
(#25, #52), #19);
```

where we can find a reference from #26 to #52 residing inside a container class. Following these rules and rectifying the above problems help very much in the interpretation process. Consequently the reference attributes (#nnnn) can be pointed to real Ifc2x Java objects that have already been interpreted and added to a Hash Map, where the line number identifier is the key and parsed object is the value, as the interpreter iterates over the array of parsed elements. In cases where a bigger identifier number exists as a reference in the arguments of the element being parsed, the IFC2x Java object would have not been yet instantiated or added to the Hash Map and consequently the reference would be pointed to a non IFC2x Java class (usually a string

attribute that was obtained from the parser). At any rate, the above mentioned two aspects; the sorting in an ascending order and the references to smaller Identifier numbers than the IFC element's own identifier had to be solved in the algorithm that interprets the STEP code. This is explained in detail in the following steps.

Step Two — Sorting the parsed array in an ascending order according to the identifier number is done by changing the array to an ArrayList and building a comparator class that is capable of sorting the list as shown in the following code:

```
package step_parser.util;
import java.util.Comparator;

public class IfcComparator implements Comparator {
      private Object elements =null;
      public int compare (Object objA, Object objB){
                  String a = ((ArrayList)objA).toArray()[0].toString();
                  String b = ((ArrayList)objB).toArray()[0].toString();

                  String a1=a.substring(1);  // to get rid of the "#"
                  String b1=b.substring(1);

                  long a2= new Long(a1).longValue();
                  long b2= new Long(b1).longValue();

                  if (b2 > a2)  return -1;
                  if (b2 < a2)  return  1;
                  return 0;                 // Elements are identical.
            }
}
```

The above comparator class is used in section two of the Interpreter class to sort the elements in an ascending order as shown in the following code:

```
package step_parser.util;
public class Interpreter
{     // Attributes
      private static boolean debug= false;
      public static STEP_PARSER st;
      static ArrayList ifc= null;
      public static Object[] elements;
//a Map between ifc_classes and their class names for instantiation
      static HashMap ifc_classes = new HashMap();
//a map between the line numbers and objects
      static HashMap ln_nrs= new HashMap();
      static private String stp_file=null;  // name of the STEP file
// for handling wrong numbering - not conforming to the ref. rules
      private static ArrayList remainings= new ArrayList();
      //Section One_____________________________________________________
      public Interpreter ( String _stp_file)
      {
            try
            {     // Parsing the STEP ISO 10303-P21 file
                  FileReader f= new FileReader(_stp_file);
                  st= new STEP_PARSER(f);
```

Section One

```
                st.ReInit(f);
                st.start();  // starting the parser
                ifc = st.ifcX;//getting the ArrayList from the parser
        //Section Two_____________________________________________________
        // 1st Step--- Sorting the ArrayList ifc using the
                        // IFC comparetor comp
                IfcComparator comp= new IfcComparator();
                Collections.sort(ifc, comp);
                elements=ifc.toArray();//getting the array of objects
        }
        catch (Exception e){
                ...
        }
        //Section Three adding the early binding classes_____________
        try
        {
        add_class ("IFCCLASS", Class.forName //Late B. Class
        ("step_parser.util.IFCCLASS"));
        add_class ("_ifcorganization",Class.forName
        ("IfcModel.IfcActorResource._ifcorganization"));
        add_class ("_ifccartesianpoint",Class.forName
        ("IfcModel.IfcGeometryResource._ifccartesianpoint"));
        add_class ("_ifclocalplacement", Class.forName
        add_class ("_ifcbuilding", Class.forName
        ("IfcModel.IfcProductExtension._ifcbuilding"));
        //...
        // Instantiationg the IFC2x model_____________________________
                instantiate();
        } //_____________________________________________________________
        catch (Exception e1) {
                ...
        }
}
//Section Four_____________________________________________________________
public void instantiate() throws InstantiationException,
                        IllegalAccessException
{
        Object[] arguments;
        for (int i=0; i<elements.length; i++)
        {
                arguments= ((ArrayList)elements[i]).toArray();
                String class_name= ((String) arguments[1]).
                toLowerCase();
                Class ifcClass = (Class) ifc_classes.get
                ("_"+class_name);
                if  (ifcClass == null)
                {
                        if (debug) System.out.println("Class is not
                        yet added, it will be casted to the IFCCLASS:
                        " + class_name); // late binding
                        try
                        {
                                ifcClass= (Class) ifc_classes.get
                                ("IFCCLASS");
                                 if (ifcClass !=null)
                                {
                                        IFCCLASS ifc= (IFCCLASS)
                                        ifcClass.newInstance();
                                        ifc.setAttributes( arguments, new
                                        Ln_Map());
                                        elements[i]=checkIFC(ifc,
                                        remainings);
                                        ln_nrs.put(((SDAI)elements[i]).
                                                getLnNr(), elements[i]);
                                }
                                else
                                {
                                        System.err.print("Permenant
```

Section Two

Section Three

Section Four

```
                                        Mapping error");
                                    // Exception is thrown
                                    return;
                                }
                        }
                        catch (Exception e){
                                ...
                        }
                } // if the classes are already early binded
                else    // we make a new instance of the class
                {
                        try
                        {
                                SDAI ifc= (SDAI)ifcClass.newInstance();
                                ifc.setAttributes(arguments);
                                elements[i]=checkIFC(ifc, remainings);
                                ln_nrs.put(((SDAI)elements[i]).getLnNr
                                        (), elements[i]);
                        }
                        catch(Exception e)
                        {
                                e.printStackTrace();
                        }
                }
        }//Section_Five_____________________________________________
        // Rectifying the referencing
        Object[] ob= remainings.toArray();
        for (int b=0; b< ob.length; b++)
        {
                if(ob[b]instanceof SDAI)
                {
                        ob[b]=ln_nrs.get(((SDAI)ob[b]).getLnNr());
                        Object[] att=((SDAI)ob[b]).getAttributes();
                        for (int j=1; j < att.length; j++)
                        {
                                if (att[j] != null && att[j].toString
                                        () .startsWith( "#"))
                                {
                                        SDAI s=(SDAI)ln_nrs.get((SDAI)att
                                                [j]);
                                        att[j]=s;
                                }
                        }
                        ((SDAI)ob[b]).setAttributes(att,new Ln_Map());
                }
        }
}
// Section six Checking the arguments_____________________________
private SDAI checkIFC(SDAI ifc, ArrayList remainings)
{
        Object[] args= ifc.getAttributes();
        for (int v=2; v< args.length; v++)
        {
                if (args[v]!= null && (args[v].toString()).startsWith
                ("#"))  // case of reference
                {
                        SDAI s=((SDAI)ln_nrs.get(args[v]));
                        if (s!= null) args[v]=s;   // replacement
                        else
                        {
                                remainings.add(ifc);
                        // for later rectification
                        }
                }  // case of a null reference
                else if (args[v]!=null &&(args[v].toString()).
                CompareTo("$")==0) // null value
                {
                        args[v]=null;
```

Section Four

Section Five: Rectifying the References

Section Six: Checking the arguments

```
                }      // case of a container class
                else if (args[v] instanceof ArrayList)
                {
                      Object[] agg=((ArrayList)args[v]).toArray();
                      ArrayList ne= new ArrayList();
                      // the replacement
                      for (int t=0; t< agg.length; t++)
                      {
                            if ((agg[t].toString()).startsWith("#"))
                            // case of reference
                            {
                                  SDAI s=((SDAI)ln_nrs.get(agg[t]));
                                  // replacement
                                  if (s!= null) agg[t]=s;
                                  else
                                  {      // to rectify referencing
                                        remainings.add(ifc);
                                  }
                                  ne.add(agg[t]);
                            }      // null references
                            else if ((agg[t].toString()).compareTo
                            ("$")==0) // case of a null value
                                  {
                                        agg[t]=null;
                                        ne.add(agg[t]);
                                  }
                            else
                            ne.add(agg[t]);  // case anything
                      }
                      args[v]=ne;   // replacing the ArrayList
                }
                else args[v]=args[v];
          }
          ifc.setAttributes(args,null);
          return ifc; //_____________________________________________
    }
```

Section Six: Checking the arguments

Section one of the code shows how the STEP_PARSER class is used to parse a given IFC/STEP -P21 file.

Section two shows the use of the IfcComparator class to sort the list according to an ascending order.

Section three of the code shows the addition of the early binding IFC2x classes together with the late binding IFCCLASS to a HashMap, where the name of the class in lower case preceded by a "_" is used as a Hash Key. The HashMap is used to make new instances of the classes at runtime, while iterating over the elements obtained from the parser, as shown in detail in section four.

Section four of the code shows both the early and late binding instantiation of the IFC2x Java classes. The interpreter iterates over the array of elements obtained from the parser (the IFC2x model), then over the attributes of each element (the 2nd dimension of the array, figure 5.24) i.e. the arguments. The first element in the array (element zero) is always the line number identifier (e.g. #50). The second element in the arguments array is always the name of the EXPRESS entity (IFC element, *"IFCxxx"*) and the rest are the entity's parameters e.g.

```
#50 = IFCSHAPEREPRESENTATION (#25, 'Body', 'SweptSolid', (#49));
```

Hence, if an already defined early binding class exists in the classes Hash Map (from section three of the code), a new early binding instance is created at run-time and the rest of the arguments are used as input parameters to the *setAttributes* method. The new instance is added to another HashMap *"ln_nrs"*, where the HashKey is the Identifier number (#nnn) and the value is the newly instantiated object at runtime.

Section five of the code is executed as a last step in the interpretation process for the rectification of any violation to the to referencing conventions. It establishes the references to the objects that were not instantiated in due time at the interpretation process later at the end, when all the new instances have already been instantiated. This is explained below and in the flow chart in figure 5.31 and its describing text.

Section six of the code contains the method checkIFC that shows how the null attributes, references to other objects and the container classes' attributes are instantiated. It should be noted that elements are stored in a HashMap *"ln_nrs"*, where they can be retrieved by line number identification. This enables the referencing from one element to another. Since, element zero of the arguments array is the line number identifier, element one is the name of the EXPRESS entity (IfcXXX) and the rest of the array's elements are the values of the attributes of the EXPRESS entity, the looping starts at 2 and not at element zero in the checkIFC method. The code checks if the element is a container class, a null reference or a reference to another object (e.g. #xxx). As earlier mentioned, references to other elements are substituted by objects

obtained from the HashMap that is instantiated at runtime (*ln_nrs*). In case that one of the arguments is a container class, the same procedure is repeated with each element of the container class.

Figure 5.31 shows a flow chart for the interpreter, where the interpretation process begins with iterating over the parsed array of elements. If the element iterated upon already exists in the IFC2x model (early binding), then a new instance is created with the given parameters. If not, it will be instantiated as a late binding class. In both cases, before the instantiation takes place, the interpreter iterates over the arguments and makes an argument checking for each element in the 2nd dimension of the array i.e. the attributes of the IFC STEP entity. If it is a "$", then it is substituted by a null value. If it is a "#nn", then the identified element is sought from the identifiers HashMap (ln_nrs). If it already exists i.e. already interpreted, then a reference to it replaces the identifier and if not, then it is added to the remainings list, where it will be later referenced to the correct element at the end of the interpretation process. In case where the argument is a container class (a Set or a List and so forth), the interpreter iterates over its elements (in this case as the 3rd dimension of the Array in figure 5.24) and treats them as normal arguments. In general, if the argument is not an identifier, a "$" or a container class, then the value of the argument is taken as a parameter for the construction of the new instance of the Ifc2x Java class, bearing in mind the mapping between EXPRESS data types and Java data types

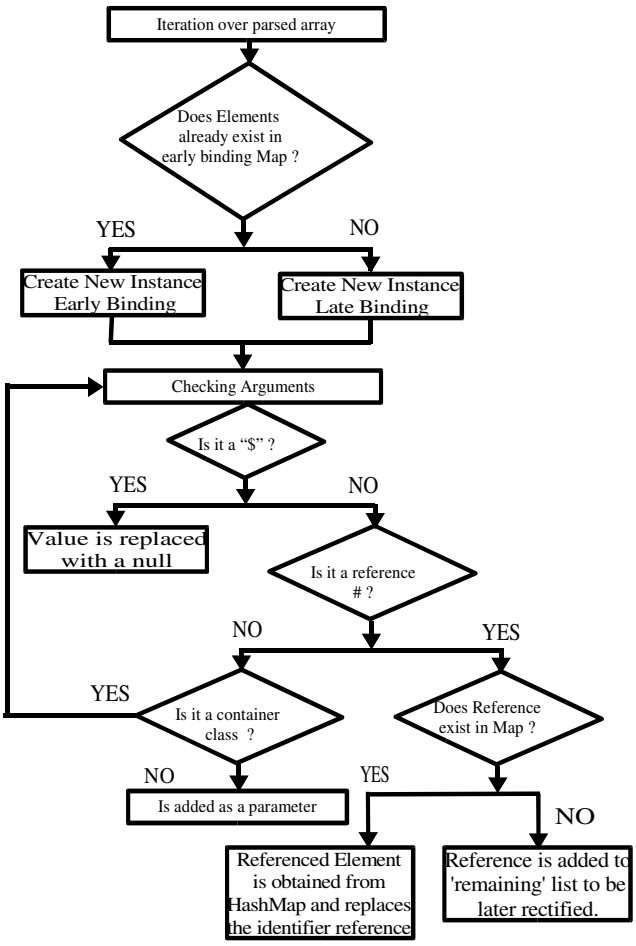


Figure 5.31 IFC2x Interpreter's flow chart

that has been earlier explained. At the end of the interpretation process, the elements in the *remainings* list are re-instantiated, where any identifier reference should be replaced with a reference to an element (IFC2x Java Object) obtained from the identifiers (*ln_nrs*) Hash Map. In this way, any violation to referencing conventions is rectified. In other words, the instantiation of such elements is done by postponing them till the end, when all the references to the elements already exist in the identifiers HashMap.

5.5.3 Visualisation

The next step after interpreting the parsed STEP file is the visualisation of the IFC model. The author thought it might be a good idea to visualise the model in three ways. The first way is the IFC Project tree hierarchy, the second way is the CAD view of the Model and the third way is the STEP model entities themselves. The three types of visualization can be viewed independently or combined together, e.g. figures 5.32 and.5.33. In all cases the aim of the visualisation is to navigate through the model and explore its elements in a way that enables managing the model and carrying out any instantiation, updating or deletion processes.

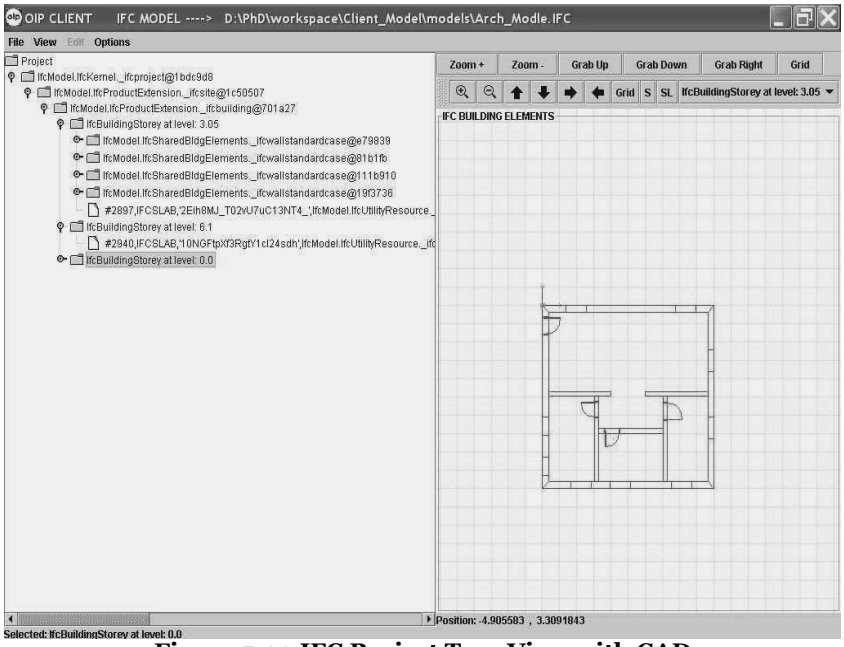


Figure 5.32 IFC Project Tree View with CAD

5.5.3.1 Project Tree View

The main spatial hierarchy of the IFC model is defined as "A *breakdown of the project model*

into manageable subsets according to spatial arrangements". There exists other decomposition structures for a project (other than the Project spatial structure). However, the spatial structure is considered by the IAI to be common to most disciplines and design tasks. It is therefore seen as the primary structure for building projects in addition to its necessity to the data exchange process. (IFC2x Model Implementation Guide 2002)

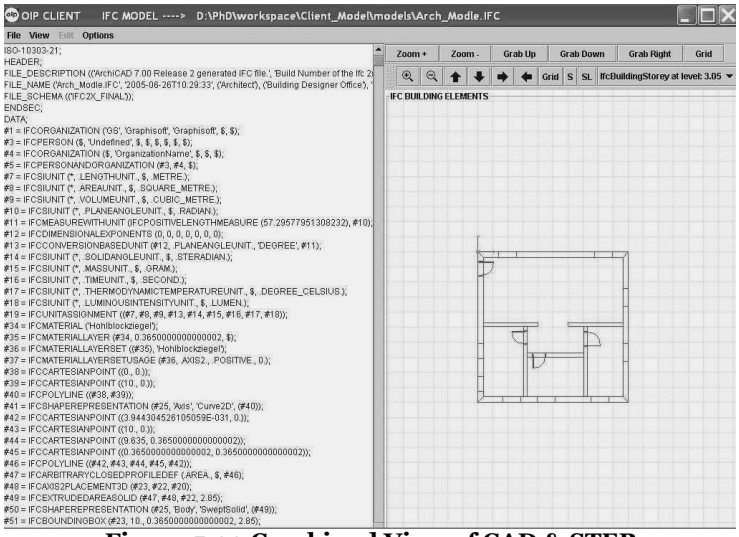


Figure 5.33 Combined View of CAD & STEP

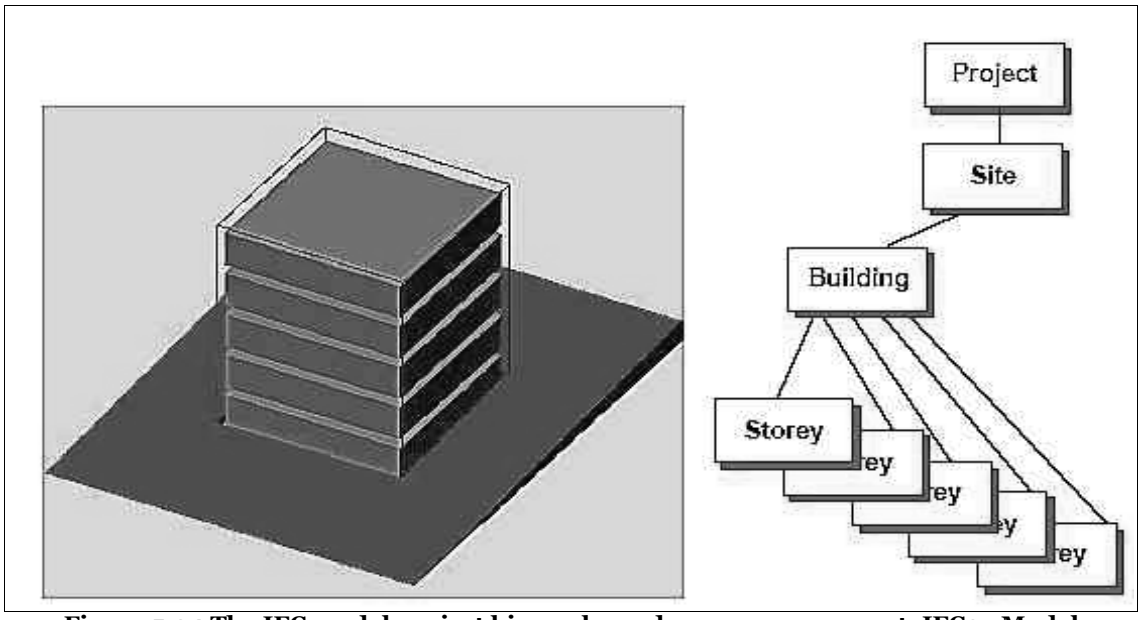


Figure 5.34 The IFC model project hierarchy and space arrangement, IFC2x Model Implementation Guide 2002

Figure 5.34 shows the hierarchical structure and spatial arrangement of the IFC model. The root of this tree is the Project entity, where it is a single unique object that contains zero or more sites. Each project contains one or more building(s) and each building contains one or more storey(s). The mandatory and optional levels of such a tree structure are shown in figure 5.35. Whereas the IfcProject, IfcBuilding and IfcBuildingStorey are mandatory levels for the exchange of complex project data, the IfcSite and IfcSpace represent optional levels (which may be provided, if they

contain necessary data).

Each instance of IfcProject, IfcSite, IfcBuilding, IfcBuildingStorey, IfcSpace- as shown in figures 5.37 and 5.38- is connected to other instances of the spatial structure by an instance of IfcRelAggregates, where the RelatingElement points to the element at the higher level and the one to many RelatedElements point to a set of elements at the lower level of the hierarchy.

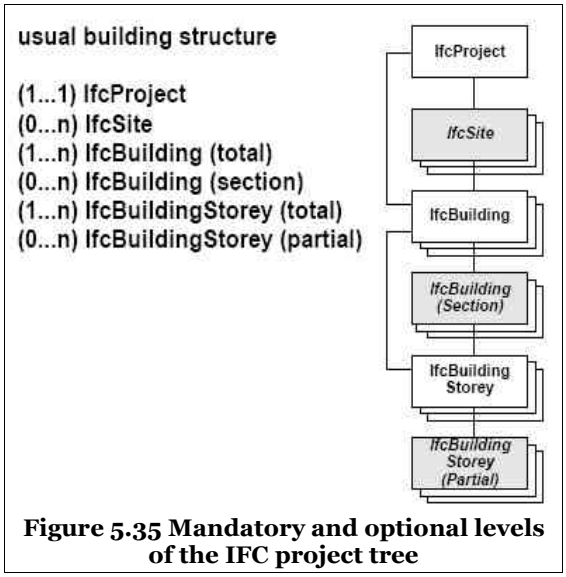


Figure 5.35 Mandatory and optional levels of the IFC project tree

Figure 5.37 shows the use of the IfcRelAggregates to define a spatial structure of a building project (in figure 5.36) having a single site with one building. The building is further divided into two building sections. Two stories are assigned to the first building section and three stories are assigned to the second building section as shown in figure 5.36

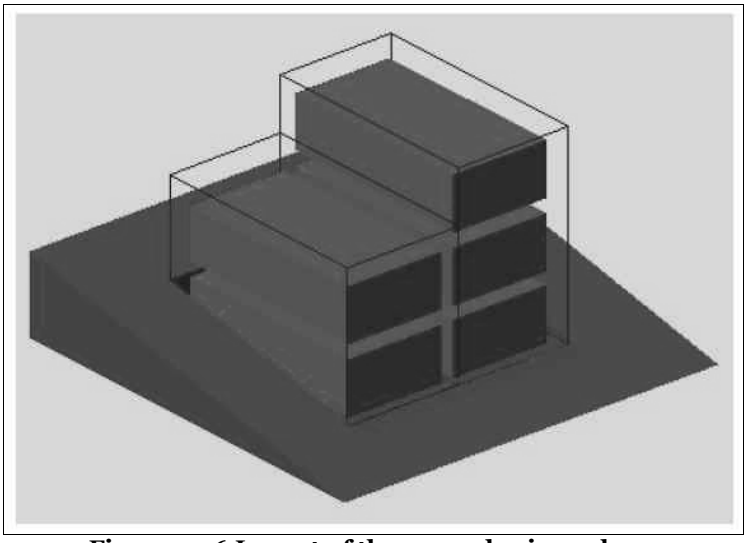


Figure 5.36 Layout of the example given above

Figure 5.37 also shows a vertical and horizontal division of the building. In such cases, the horizontal division (into building sections) takes priority and the building stories are later assigned to the sections. A building storey that physically spans through two building sections would therefore be subdivided into two building stories, and each then assigned to a single building section.

The reader who needs to have an idea about the above mentioned IFC2x elements (IfcProject, IfcSite, IfcBuilding, IfcBuildingStorey) is strongly advised to refer to the IFC2x Model Implementation Guide. In the scope of this section only the IfcRelAggregates is explained due to the fact that it plays an important role in joining the project's parts together.

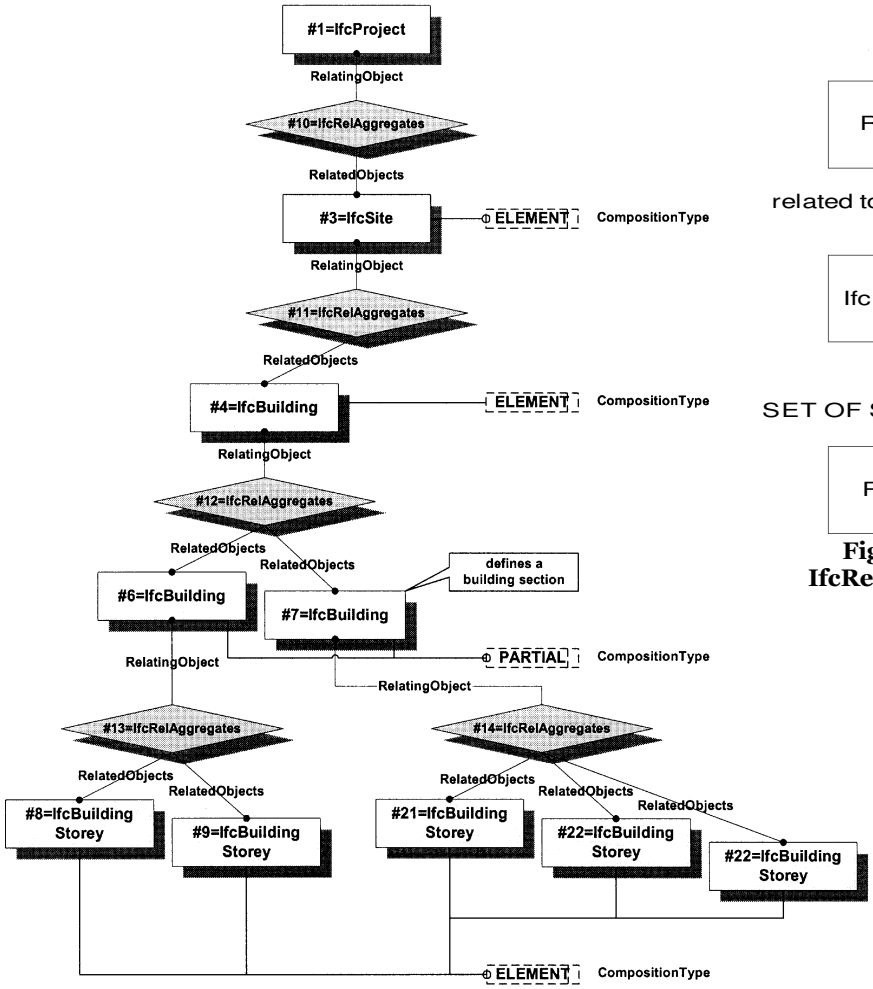


Figure 5.37 The decomposition of the IFC Spatial Structure, IFC2x Model Implementation Guide 2002

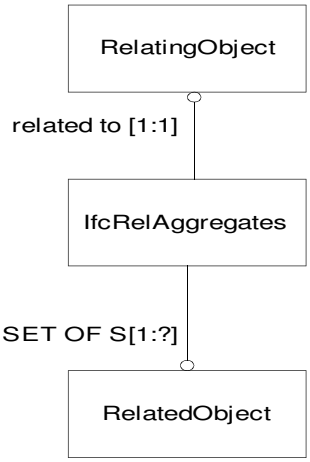


Figure 5.38 IfcRelAggregates

IfcRelgregates— The aggregation relationship *IfcRelAggregates* is defined by the IAI as *"A special type of the general composition/decomposition (or whole/part) relationship."* It has a *relatingObject* attribute that references the entity that is being divided (any subtype of *IfcObject* e.g. IfcBuilding) and a *relatedObjects* attribute that references a set of objects that belong to the relatingObject (a set of *IfcObject* subtypes, e.g. IfcBuildingStories). Figure 5.38 shows an EXPRESS-G diagram of such a relation[13]. The following code extract is its

13 This EXPRESS-G diagram is developed by the author for clarification.

EXPRESS ISO 10303-P11 definition:

```
ENTITY IfcRelAggregates;
RelatingObject   :   IfcObject;
RelatedObjects   :   SET [1:?] OF IfcObject;
END_ENTITY;
```

The following section describes an algorithm for building the project tree view according to the earlier described IFC hierarchy and the flow chart in figure 5.39. Readers interested in the technicalities of the solution can refer to appendix C (step_merger.util.ProjectTree). The algorithm begins by iterating over the elements of the IFC model and looks for the entity with the name *"IFCPROJECT"* (a unique entity). It makes the project entity the root node of the tree. In the second step, it iterates over the IFC model and looks for the *"IFCRELAGGREGATES"* instance that contains the "*IFCPROJECT"* instance as its relating Object attribute. It should be noted that the search for the objects is done in this way because the INVERSE attributes of the objects themselves are not mapped into the STEP file, as earlier explained. Consequently the only way to discover the relation between objects is through the instances of the objectified relationship class "*IfcRelAggregates"*. Once the relation is found, the related objects whether they are sites or building, are added as child nodes to the project node. In the third step the algorithm looks for instances of IFCSITE (if there is any) and adds them as children nodes to the project node. The fourth step is adding the building nodes to the project or site. The fifth step is adding building storeys to the the building nodes. The sixth step is adding the building elements e.g. Walls, doors and windows to each building storey.

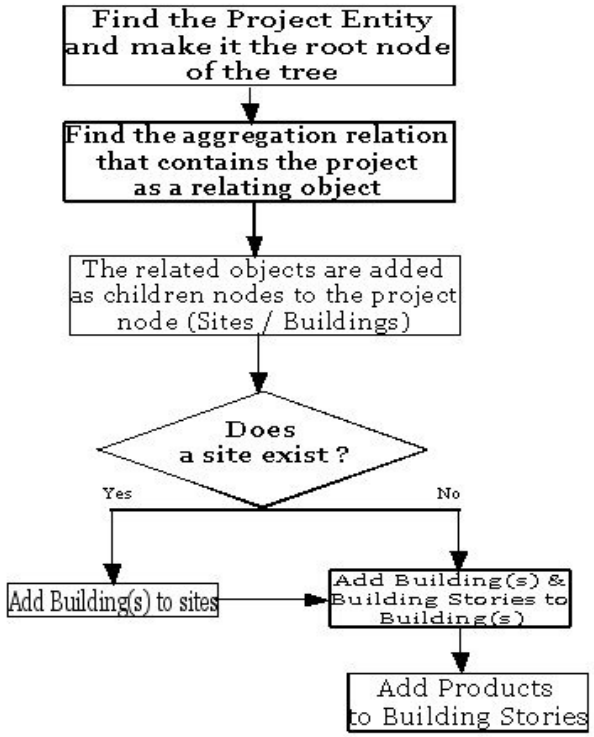


Figure 5.39 The Project Tree Viewer flow chart

In the scope of this research work, presenting the IFC model in its Project Tree view is not considered to be the aim by itself. However, it is just a means that enables the navigation through the model and hence carrying out information queries and updates on the selected elements of the building information model. Therefore, introducing other product attributes like property sets, property definitions, materials, classifications are of paramount importance to the goals of this research work. Accordingly, the project tree is extended to include the above mentioned aspects. Things such as the products' attributes like the dimensions of a door or a window, the construction materials included in such elements and so forth are included in the tree view. In other words, the attributes that contribute to the conduction of parametric searches are also included. It could be navigated through these parameters as desired by just expanding the product's tree node, as shown in figure 5.40. The following algorithm shows the steps of adding the attributes of an IfcDoor to the project tree upon its selection (expansion): First the attributes of the selected product are added to the "Attributes" tree node (e.g the width and height of the IfcDoor in figure 5.40). The next step is the addition of the property sets that belong to this door. This is done by searching for the relation *"IfcRelDefinesByProperties"* that has this door as a an element in its related object set of elements. This is a rather complex process, due to the fact that we have to iterate over the whole

Figure 5.40 A snap shot showing the tree-view GUI

model, find each instance of the *"IfcRelDefinesByProperties"*, cast it to its early binding Java class, search the elements related to it by iterating over the elements in its "*RelatedObjects"* attribute (which is a *Set*). The selected element's hash code is compared with the ones in the *relatedObjects Set*. If they are identical, then this is one of the property sets that belongs to this product (IfcDoor). This process is repeated with every *"IfcRelDefinesByProperties"* in the whole IFC model. Moreover, it should be differentiated between two types of property sets; single value and complex property sets. The complex property sets contain more than one single value property set. This would require a complete explanation to property sets in the IFC model, where there is not enough space to do this inside this work. At any rate, the reader is advised to consult the (IFC2x implementation Guide 2004) for further information. The class step_merger.ui.Select_Panel in Appendix C shows the complete technical implementation of the above mentioned algorithm.

After adding the property sets to the product in the project tree, the property definition (if exists) should be added as well. A property definition can include things like the way of operation of a door or a window panel, their construction materials and so forth. The same algorithm is nearly used. During the iteration over the elements, if the element is an instance of "IfcRelDefinesByType" and one of the elements in its related objects set is the selected object in the project tree in figure 5.40, then the type definition is found (e.g. IfcDoorStyle or IfcWindowStyle and so forth) and its attributes (e.g. operation and construction of the door) are added to the tree.

After adding the attributes, property sets and the property definition to the tree, the classification of the product has to be added. The following algorithm delivers a set of all the classifications that belong to a selected product. It begins by iterating over all the elements in the model looking for the IfcRelAssociateClassification instances. Once an instance is found,the related objects set is iterated upon and it is examined, if the selected product is a candidate of this set or not. If this is true, the classification notations are added to the tree node.

Further more the same algorithms are used to build the tree view of the construction materials, as seen in figure 5.40. Some minor changes are made to the algorithm due to the differences in the inheritance tree of elements that belong to the resources layer of the IFC2x model, e.g. IfcMaterial. For further details about this issue the reader should refer to the IFC2x model Implementation Guide.

5.5.3.2 CAD View

The aim of the CAD view in this work is to visualize the IFC model in an attempt to be able to navigate through it and select its elements (construction products). The CAD view works in conjunction with both the Project Tree View and the STEP View to establish a project overview that can give a good grasp of the IFC model. It brings an image or a geometrical representation of the product that is being specified. The Project Tree View resembles working with building specifications and adding the CAD view widens the scope, as if the specifier is working simultaneously with both specifications and drawings at the same time. In the current version of the software development related to this work, the representation of building elements is limited to a few elements, namely: building storeys (*IfcBuildingStorey*), walls (*IfcWallStandardCase*), openings (*IfcOpening*) and doors (*IfcDoor*) and its styles. Furthermore, the representation is limited to a 2D representation. In general, the same concepts of geometrical representation and location in the coordinate space applies for all the construction products elements in the IFC model i.e. all elements that belong to the IFC EXPRESS schema *IfcSharedBuildingElements*. The Java2D package is used for the geometrical visualization of the model with the aim of visualization only and not carrying out any CAD functionalities, except for the selection, zooming in and out, supplying a scaled grid in the x and y axis plane, origin arrows pointing to the orthogonal coordinate system and so forth.

This section does not discuss the basics and details of CAD applications and the Java2D package, as they are not the aim of this work by themselves. The reader can refer to (Foley et al, 1996), (Hardy, 2000) and (Firmenich, 2004) for such aspects where geometrical modelling in CAD is

described and discussed in detail. On the other hand, the light is focused upon the extraction of of the geometrical representation data and the location of elements in the coordinate space from the IFC model in a manner that enables a representation that helps achieving the aim and objectives of this research work .

Generally speaking, any leaf object derived from the IfcProduct entity in the IFC model can have zero or more geometrical representations. It is worth also mentioning that the geometrical representation can be context dependent. This can be very useful in cases where, for example, the geometrical model is dependant on the scale of the drawing or the AEC discipline that is being represented and so forth. The IfcRepresentationResource schema of the IFC model holds all the entities that are related to the geometrical representations and the references to the representation contexts. It is also worth mentioning that if a representation is given to any subtype of IfcProduct , then the object placement must be defined as well.

The following code cut-out shows the geometrical representation and location of an IfcWallStandardCase in the IFC-EXPRESS definition and how it is mapped to the STEP file:

```
-- The EXPRESS definition
ENTITY IfcWallStandardCase;
  ENTITY IfcRoot;
       (...)
  ENTITY IfcObject;
       (...)
  ENTITY IfcProduct;
  ObjectPlacement    :   OPTIONAL IfcObjectPlacement;
  Representation     :   OPTIONAL IfcProductRepresentation;
  INVERSE
       (...)
  ENTITY IfcElement;
       (...)
  ENTITY IfcBuildingElement;
       (...)
END_ENTITY; -- IfcWallStandardCase
-- And the IFC-STEP File is exchanged as:-----------------------------
#57 = IFCWALLSTANDARDCASE ('3e_at4omrAcOTZok1_wgCg', #6, 'Wand-  006', $,
      $, #56, #54, $); -- (#56= placement, #54 rep.)
#56 = IFCLOCALPLACEMENT ($, #55);
#54 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#41, #50, #53));
#55 = IFCAXIS2PLACEMENT3D (#23, #22, #20);
-----------------------------------------------------------------
```

The element that has the identifier #56 represents the Object Placement of the

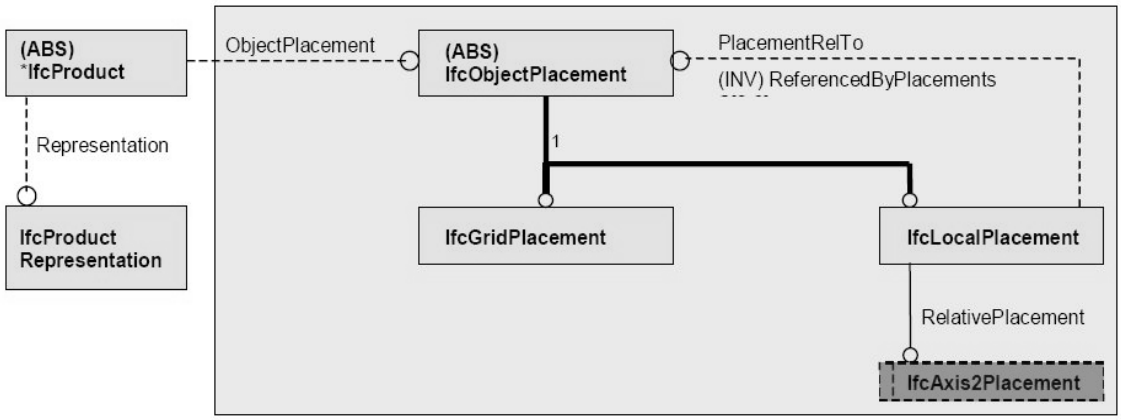


Figure 5.41 An EXPRESS-G Diagram showing the product placement in the coordinate system

IfcWalllStandardCase in the spatial context. This placement can either be absolute (relative to the world coordinate system), relative (relative to the object placement of another product) or constrained (e.g. relative to a grid axes). Meanwhile, the IfcProductDefinitionShape (#54) is considered to be the container of potentially arbitrary number of geometric representations that are context dependent, in this example they are the elements with the identifiers #41, #50 and #53 (they are not included in this code cut-out, but explained in full detail at the geometrical representation section of this chapter).

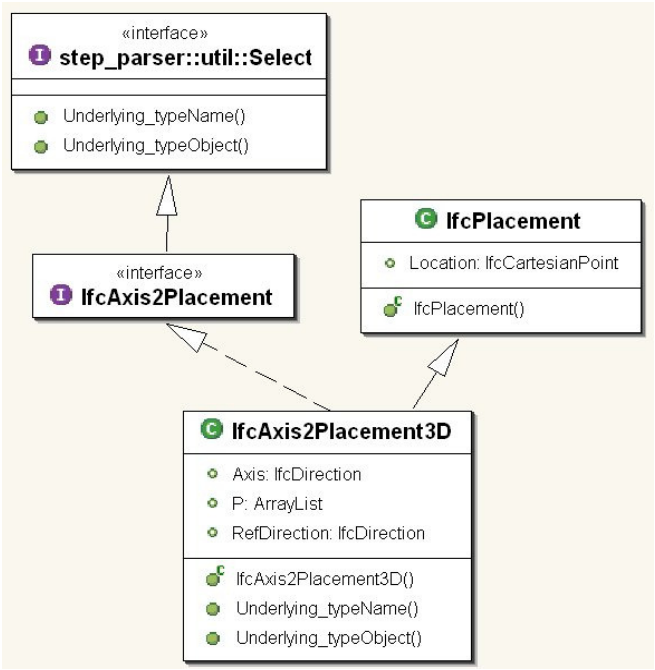


Figure 5.42 A UML Diagram for the IfcAxis2Placement, (Nour 2005)

Figure 5.41 shows an EXPRESS-G diagram representing the relation between the IfcProduct and its subtypes and their placement attributes. The object placement defines the object's coordinate system according to a Grid or a local placement. In the scope of this work, only the local placement is discussed. It is differentiated to either two-dimensional axis placement

(*IfcAxis2Placement2D*) or a three dimensional axis placement (*IfcAxis2Placement3D*). Both *IfcAxis2Placement2D* and *3D* are subtypes of the *SelectType IfcAxis2Placement* and the entity *IfcPlacement* at the same time, as shown in the following EXPRESS definitions:

```
TYPE IfcAxis2Placement = SELECT
(IfcAxis2Placement2D, IfcAxis2Placement3D);
END_TYPE;
ENTITY IfcPlacement;
Location   :   IfcCartesianPoint;
DERIVE
Dim   :   IfcDimensionCount :=  Location.Dim;
END_ENTITY;
-------------------------------------------------------------------------
ENTITY IfcAxis2Placement3D  SUBTYPE OF (IfcPlacement);
Axis   :   OPTIONAL IfcDirection;
RefDirection   :   OPTIONAL IfcDirection;
DERIVE
P  :  LIST [3:3] OF IfcDirection :=  IfcBuildAxes(Axis, RefDirection);
WHERE
(...)
END_ENTITY;
```

This represents some sort of multiple inheritance that is solved in Java by extending the early binding class *IfcPlacement* and implementing the interface *IfcAxis2Placement* (corresponding to the IFC-EXPRESS Type *IfcAxis2Placement*) that extends the *Select* Interface according to the UML diagram in figure 5.42:

Definitions of the IfcAxis2Placement3D:

1- The EXPRESS entity definition:

```
ENTITY IfcAxis2Placement3D
      SUBTYPE OF (IfcPlacement);
      Axis               :   OPTIONAL IfcDirection;
      RefDirection       :   OPTIONAL IfcDirection;
      DERIVE
      ...
      WHERE
      ...
END_ENTITY;
```

2-The STEP Mapping of the EXPRESS entity. The following STEP code is an example from an exchange file that shows the mapping of the above EXPRESS definition. (It includes a Cartesian point (inherited from *IfcPlacement*) and two direction vectors, that define the product's placement in the co-ordinate space).

```
-- Extract from an IFC-STEP ISO 10303 P-21 file
#140 = IFCCARTESIANPOINT ((0.0, 0.0, 0.0));
#145 = IFCDIRECTION ((0.0, 0.0, 1.0));
#150 = IFCDIRECTION ((1.0, 0.0, 0.0));
#155 = IFCAXIS2PLACEMENT3D (#140, #145, #150);
```

3- Definition from ISO 10303-42:1992: *"The location and orientation in three dimensional space of three mutually perpendicular axes. An axis2_placement_3D (IfcAxis2Placement3D) is defined in terms of a point (inherited from IfcPlacement supertype) and two (ideally orthogonal) axes. It can be used to locate and originate an object in three dimensional space and to define a placement coordinate system. The entity includes a point which forms the origin of the placement coordinate system. Two direction vectors are required to complete the definition of the placement coordinate system. The axis is the placement Z axis direction and the ref_direction (RefDirection) is an approximation to the placement X axis direction."*

By looking again at the above IFC-EXPRESS definition of the entity *IfcAxis2Placement3D,* the corresponding code in the STEP file and the definition from the ISO 10303 p-42 (1994), we could notice that each product has its own coordinate space which is either relative to the world coordinate system or to a location of another product, for a example the location of an opening relative to wall.

```
-- EXPRESS definition of a local placement
ENTITY IfcLocalPlacement;
      PlacementRelTo   :   OPTIONAL IfcObjectPlacement;
      RelativePlacement   :   IfcAxis2Placement;
END_ENTITY;
```

Each local placement is given by an axis placement, which can be either a 2D or a 3D axis placement and another placement relative to it. If the optional PlacementRelTo attribute is not assigned to a value, the reference is forwarded to the origin of the world coordinate system. On the other hand the RelativePlacement attribute is defined using the abstract IfcAxis2Placement entity that is specialized to a 2D or 3D axis. As it can be observed from the previous STEP code extract, the IfcAxis2Placement3D consists of three attributes (a Cartesian point and two direction vectors).

```
/* Definition of the world coordinate system */
```

```
#1=IFCGEOMETRICREPRESENTATIONCONTEXT($, '3Dmodel', 3, 1.0E-005, #2, $);
#2=IFCAXIS2PLACEMENT3D(#3, $, $);
#3=IFCCARTESIANPOINT((0.0, 0.0, 0.0));
```

Defining the world and local coordinate systems: As it can be seen from the above code, #1 defines the world coordinate system. The first optional attribute is a context identifier for a context within a project. The second attribute is the context type (2D or 3D). The third attribute is the coordinate space dimension. The fourth attribute is the model precision value, it is a double (REAL) value, typically in the range of 1E-5 to 1E-8, that indicates the tolerance under which two given points can be assumed to be identical. The fifth attribute establishes the world coordinate system for the representation context used by the project, it uses an IfcAxis2Placment instance for such a definition, in this example it is a 3D case. The sixth attribute is optional and represents the True North direction relative to the world coordinate system as established by the representation context.

For further detailed information about the placement of products in the co-ordinate space of the IFC2x model the reader should refer to the Ifc2x Model Implementation Guide and (Nour 2005). Nevertheless, it is necessary in the scope of this work to mention the following rules that are applied to the referencing of placements to enable the reader to have an overview of the CAD visualization algorithm. It should be noted that the reference is cyclic and has the following characteristics for the subtypes of *IfcProduct:*

- The IfcSite is placed absolutely within the world coordinate system established by the geometric representation context.
- The IfcBuilding(s) is placed relative to the local placement of the IfcSite.
- The IfcBuildingStorey(s) is placed relative to the local placement of IfcBuilding.
- All subtypes of IfcElement are placed relative to the local placement of their containers (normally to *IfcBuildingStorey* but possibly also to *IfcSite, IfcBuilding*), or to the local placement of the IfcElement to which it is tied by a relationship (e.g. *IfcRelVoidsElements, IfcRelFillsElements, IfcRelCoversBuildingElements,*

IfcRelAssembels).

Defining the geometrical representations of products: All the above discussions were about setting the location of the IfcElements in the world coordinate system of the IFC2x model. The next task is the graphical representation of such elements. In the scope of the IFC model, the following representation types are distinguished (Curve2D, GeometricSet, GeometricCurveSet, SurfaceModel, SolidModel and its subtypes (Brep, SweptSolid, CSG , Clipping), BoundingBox, and SectionedSpine).

In the scope of this work, only the SolidModel representations and particularly the SweptSolid is required to extract the needed information for the 2D representations that serve the objectives of the research work. The BoundingBox representation could also have been used. However, due to the fact that it is an additional representation (optional), it can not be relied upon for extracting the graphical representations of the IFC elements. Furthermore, it does not represent the details of the objects. It only represents the external boundaries of the element in the form of a cube or a cuboid. Thus, the SweptSolid representation is considered by the author to be the most suitable representation that satisfies the needs of graphical representation in this work and hence, is discussed in some detail. For more information about the other representation types the reader should refer to the IFC2x Model Implementation Guide.

The SweptSolid representation provides a geometrical representation based on sweeping a profile (given by a planer bounded area), where there are two different types of planar operations. The first is the linear extrusion and the second is the revolution. In the scope of this work, only the first type is discussed. Nevertheless, the position of the swept body depends on the axis placement of the swept area solid, where the XY plane of the placement is used to place the profile. The IFC entity that is used for extruding the swept profile is called *IfcExtrudedAreaSolid* which is a subtype of *IfcSweptAreaSolid*.

```
ENTITY IfcSweptAreaSolid;
```

```
      SweptArea  :   IfcProfileDef;
      Position   :   IfcAxis2Placement3D;
END_ENTITY
ENTITY IfcExtrudedAreaSolid;
      ExtrudedDirection   :   IfcDirection;
      Depth               :   IfcPositiveLengthMeasure;
WHERE
      WR1   :   IfcDotProduct(SELF\IfcSweptAreaSolid.Position.P[3],
      ExtrudedDirection) <> 0.0;
END_ENTITY;
```

Generally speaking, the extruded area solid defines the extrusion of a 2D area (given by a profile definition) by a direction and a depth. The result is a solid as shown in figure . The profile of the extruded area is defined in the first attribute (SweptArea). The second attribute (Position) defines the XY plane where the profile is extruded. The third attribute (ExtrudedDirection) shows the direction of extrusion, where it can be either positive or negative. The fifth attribute (Depth) is a positive length measure that gives the magnitude of extrusion. The *WHERE* rule enforces that the ExtrudedDirection shall be in the direction of the local z-axis of the coordinate system.

```
-- Setting the representation contexts...
#100 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Design', 3, 1.0E-5,
#680, $);
#175 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Sketch', 3, 1.0E-5,
#680, $);
-----------------------------------------------------------------------
--The wall's attribute, #900 refers to the shape representation...
#195 = IFCWALLSTANDARDCASE ('0ut41YbU54kw92AmTHWCZp', #200, 'Wand-006',
       $, $, #270, #900, $);
#900 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#105, #165, #180));
-- The wall is defined by 3 representations at the same time
#105 = IFCSHAPEREPRESENTATION (#100, 'Axis', 'Curve2D', (#95));
#165 = IFCSHAPEREPRESENTATION (#100, 'Body', 'SweptSolid', (#160));
#180 = IFCSHAPEREPRESENTATION (#175, '', 'BoundingBox', (#170));
-----------------------------------------------------------------------
#160 = IFCEXTRUDEDAREASOLID (#135, #155, #145, 2.7);
#135 = IFCARBITRARYCLOSEDPROFILEDEF (.AREA., $, #130);
#145 = IFCDIRECTION ((0.0, 0.0, 1.0)); -- Extrusion in z-axis
#155 = IFCAXIS2PLACEMENT3D (#140, #145, #150); -- Placement in XY Plane
-- The points of the polyline
#110 = IFCCARTESIANPOINT ((0.0, 0.0));
#115 = IFCCARTESIANPOINT ((10.00, 0.0));
#120 = IFCCARTESIANPOINT ((10.00, 0.365));
#125 = IFCCARTESIANPOINT ((0.0, 0.365));
#130 = IFCPOLYLINE ((#110, #115, #120, #125, #110));
```

Setting the Representation Context

Representation Alternatives

Extruded Polyline

Extruded Polyline

The above code represents a cut-out of an IFC-STEP file that shows an example of a wall of length 10 metres, height of 2.7 metres and width of 36.5 centimetres. The first section of the code sets the representation context, i.e. a mapping between representations and contexts. The wall's seventh attribute refers to the representations of the wall (#900), which is an entity of type

IfcProductDefinitionShape, that contains three different representations for the wall in a container class (i.e. a set that contains the elements #105, #165, #180). The first representation (#105) represents the axis of the wall. The second representation (#165) represents the wall by a swept solid and the last representation (#180) is a BoundingBox. As a result to the earlier discussion about the different representation types, the second representation is chosen and relied upon in establishing the CAD view of the walls. #160 represents the wall in an extruded area solid, where the first attribute represents the profile of the area that is being extruded by a closed poly-line that consists of four Cartesian points. The second attribute (#155) is an *IfcAxis2Placement3D* that defines the placement in the X-Y plane. The third attribute (#145) represents the extrusion in the direction of the Z-axis (positive). The last attribute is a positive length measure that represents the magnitude of extrusion.

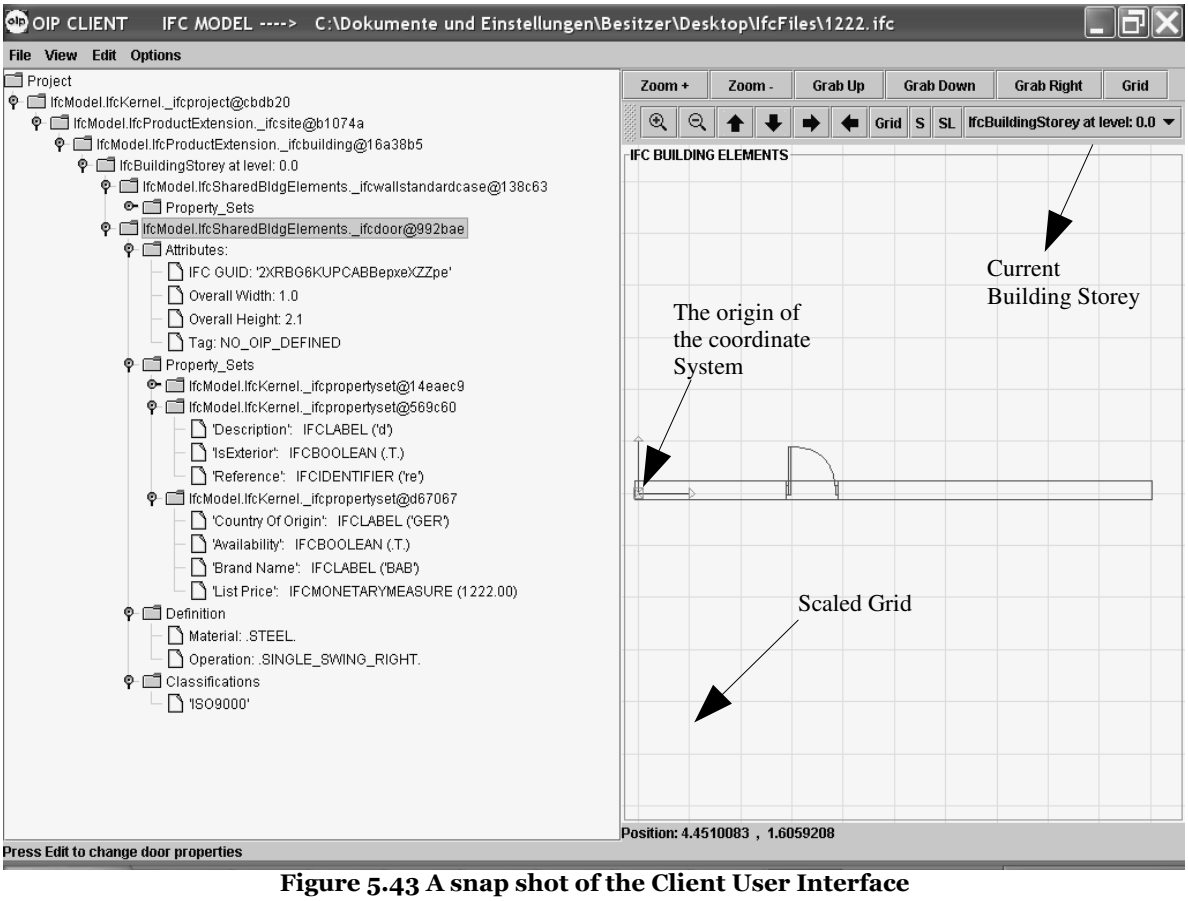


Figure 5.43 A snap shot of the Client User Interface

Having discussed the principles of product location and representation in the IFC model, it is now the turn to show, how the above algorithms are implemented in the software development to view the IFC model in a CAD view.

Figure 5.43 shows a snap shot of the client's user interface. On the left hand side is the project's tree view and on the right hand side is the CAD view for the IFC model. It represents three elements in one horizontal plane (IfcBuildingStorey at level 0.0) namely: An IfcWall, an IfcOpening and an IfcDoor.

Figure 5.44 shows a snap shot from ArchiCAD displaying the same IFC model shown in figure 5.43 by the author's software development. As earlier mentioned, it is not intended to discuss the basics of CAD visualization in this work. The goal is to demonstrate how the data is extracted from the IFC model and represented by Java.

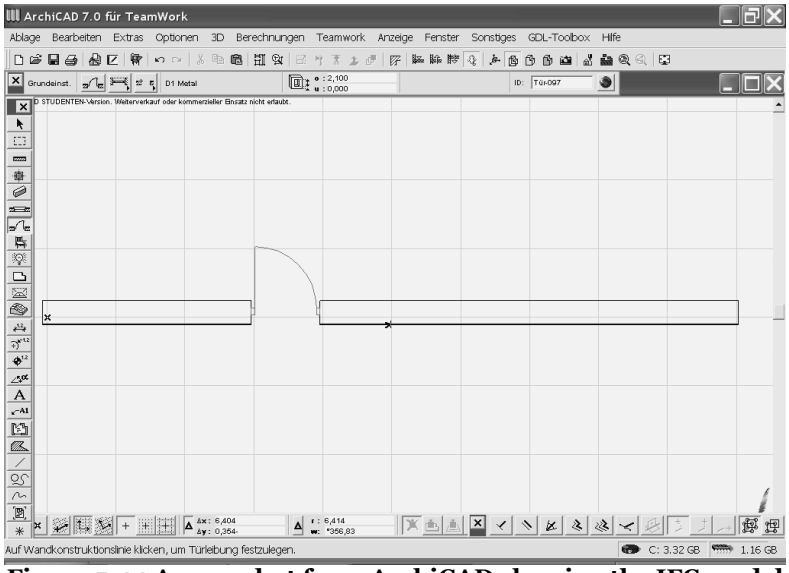


Figure 5.44 A snap shot from ArchiCAD showing the IFC model

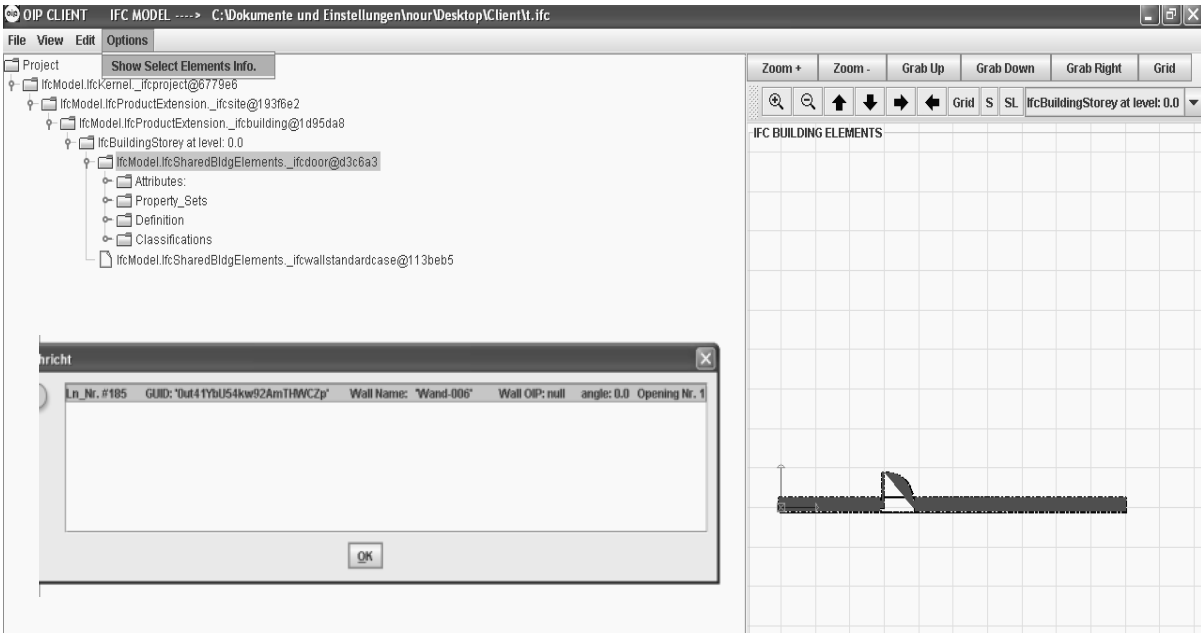


Figure 5.45.Selection of elements on the CAD View

Figure 5.45 shows how can elements be selected from the CAD view, where the properties can be

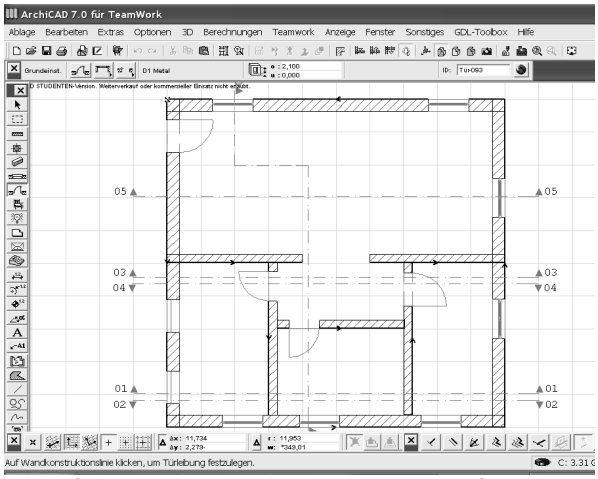


Figure 5.47 A snap shot from ArchiCAD showing the floor at level 0.0

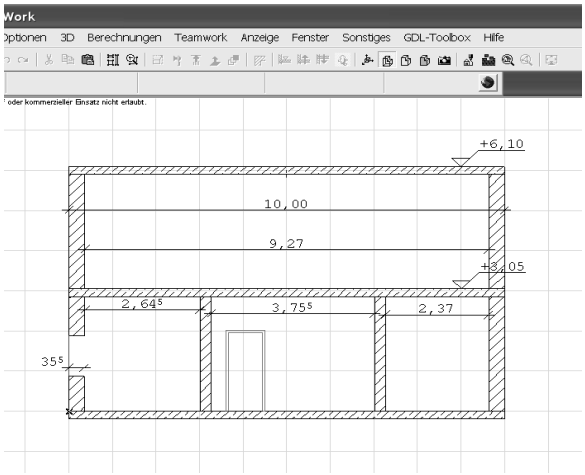


Figure 5.46 A snap shot from ArchiCAD showing vertical section 1-1 of the IFC model

displayed and operated upon (updates, deletion and instantiation). Figure 5.47 shows a more complex drawing made for demonstration reasons. It is a two storey building. The ground floor (at level 0.0) contains some walls and openings whereas the first floor is empty, as it can be seen from the vertical section (1-1) in figure 5.46. Figures 5.49 and 5.48 together with the video demonstration in (appendix C/demos/UI4/CAD) show how the software development can view the different building storeys and their constituents, one level at a time.

Figure 5.50 represents the same CAD model, but with the ground floor rotated with an angle of magnitude (45) degrees anti-clockwise around the lower left corner of the building. Meanwhile, the first floor is not rotated and is kept unchanged while both floors are displayed at the same

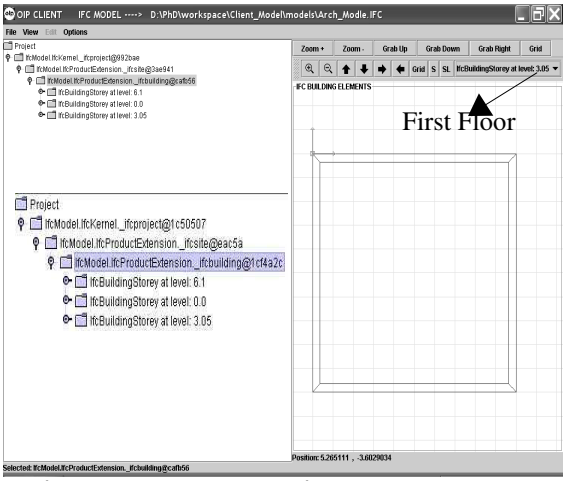


Figure 5.48 The CAD view of the Software development showing the floor at level (3.05) & its constituents

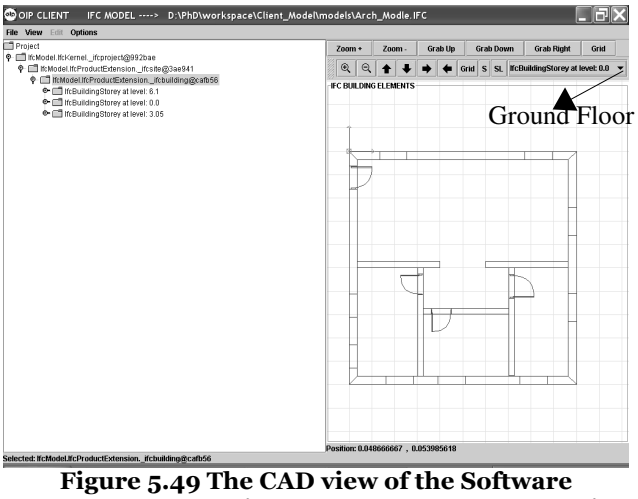


Figure 5.49 The CAD view of the Software development showing the floor at level (0.0) & its constituents

time. The first floor rotation is done intentionally to show that different levels (building storeys) can also be displayed together at the same time or one at a time.

Figure 5.51 is a zoomed-in view that shows the details of the connections between a wall, an opening and a door and how they fit together.

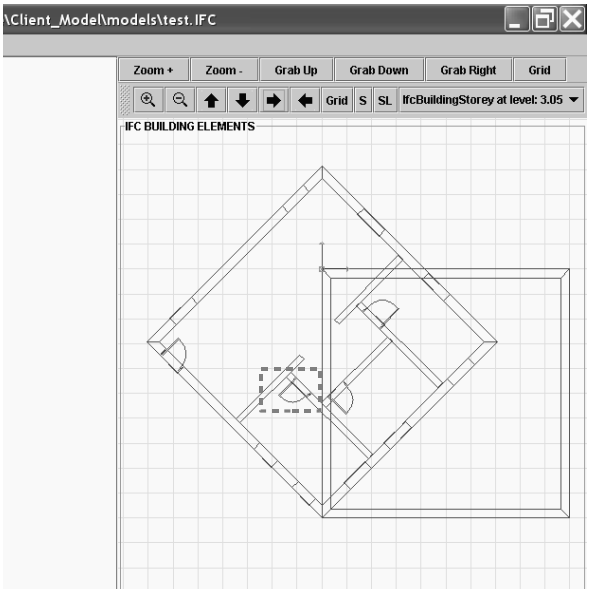


Figure 5.50 A snap shot showing the rotation of the ground floor by 45 degrees anti-clockwise

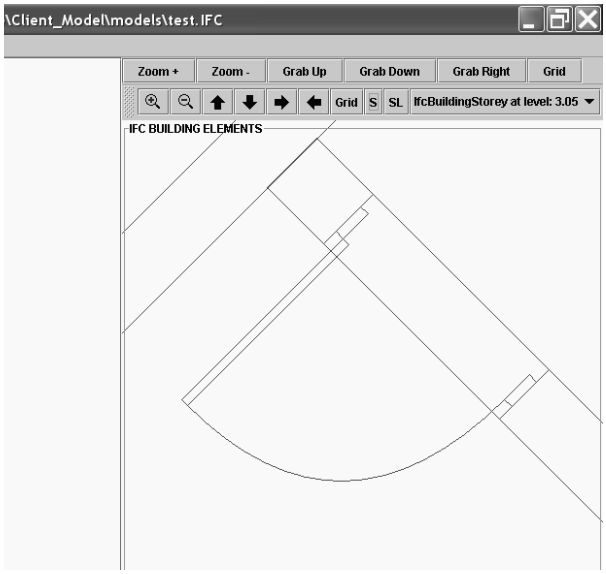


Figure 5.51 A zoomed in snap shot showing the details of connection between walls, openings & doors

Figure 5.52 shows a tree view of the Java cad package that contains all the classes related to the CAD view (in Appendix C). *Drawable* is an interface that is implemented by the descendent classes from the IFC model that contain the implementation, e.g. _ifcwallstandardcase to draw itself on the drawing panel by wrapping an object of the class Wall.

```
public interface Drawable {
      public Shape draw (CoordSpace cs ,Projection2D p, DrawableElement el);
}
```

The Manager class (shown in figure 5.53) controls and manages the coordinate space and the Projection from the world coordinates to the device coordinates in addition to all of the GUI functionalities (e.g. Listeners, actions, and so forth). The BuildingConstruction class allocates building products to building stories and gives them to the CAD viewer as an array of objects to be displayed. It navigates throughout the floors of the building with a current floor cursor. In this manner, only the constituents of the current building storey are displayed as shown in figures

5.48 and 5.49 and the video demonstration in (appendix_C / demos / UI4 / CAD), according to the code in (appendix_C /cad /util /BuildingConstruction). Furthermore, it also builds a Map between Building Storeys and their constituents (construction products and materials), where the building storey is the key and the set of constituents is the related object. It is also worth mentioning that a reverse access Map could have also been designed to satisfy query needs to the IFC model for any other intentions that are outside the scope of this work.

Figure 5.52 A tree view of the Java package related to the CAD view

The Wall class wraps two *GeneralPath* objects from the package *java.awt.geom*. One is for the wall itself and the other is for the opening, where both of them are transferred to Areas (*java.awt.geom.Area*) and subtracted by a boolean operation from one another. In the meantime, it implements the Shape interface (*java.awt.Shape*) and consequently all its methods. It draws the wall, subtracts any openings and adds any door instances that are related to it. It should also be noted, that the wall executes all the above mentioned processes in its own local coordinate system, then the whole drawing is transferred by an Affinetransform (java.awt.geom.AffineTransform) to the world coordinate space. Another approach could have been to move the world coordinate system relative to the wall's placement and draw the related elements. Nevertheless, the author thought it might be much more simpler to adopt the first approach rather than the second. However, in other applications, where the CAD functionalities have to be implemented, the second approach might be of greater use.

As it can be seen from figure 5.53 the *DrawableElement* class wraps an object that implements the *Drawable* interface to pass the drawing commands to the Wall object, in the context of this example it is the implementation class of IfcWallStandardCase (i.e. _ifcwallstandardcase) that wraps a Wall object and implements the *Drawable* interface.

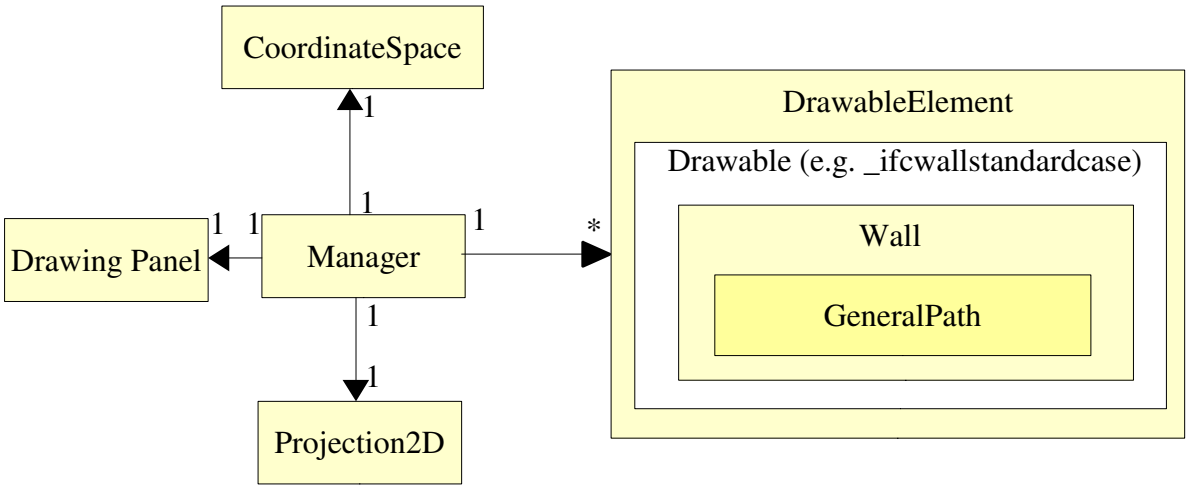


Figure 5.53 The relations and cardinalities between classes in the cad package

The Manager class controls the drawable elements through the *DrawableElement* class, which in fact wraps an element that implements the interface *Drawable*. The *DrawableElement* class has a reference to the entire IFC model and hence is responsible for providing the objects that implement the *Drawable* interface with information about their local placement and shape representations by querying the IFC model.

Until the time of writing this work, which is related to the IFC2x version of the IFC model. There is a struggle between two opinions; the first is enforcing the fact that the IFC model is object oriented and thus should only communicate information related to the model itself and not to its views. This is what the current IFC2x version supports. All details of 2D representations like line types and colours, layers and so forth are left for the Software that gets hold of the model to freely determine. This in turn results in different 2D views of the models, depending on the viewing software. The second opinion relies heavily on the fact that information in the construction industry is more often than not exchanged as 2D drawings and not as models, and hence, the exchange of 2D information in the IFC model should be normalised. It is also worth mentioning that there are some trials e.g. from (Kim et al, 2002) to incorporate 2D views of the IFC model in the IFC2x2 version.

The first view has the advantage of displaying the model in different views with a minimum of information exchange, on the other hand the presentation information from the originating system is lost. Moreover, it is worth also considering the file sizes, when all the 2D presentation information is added to the exported model. It is argued by (ibid) that the zipped IFC file can be reduced by 20% of its size and that the inclusion of such 2D representations of the model can be selected by the user to be included or excluded as needed.

5.5.3.3 STEP View

As it can be seen from figures 5.33 and 5.54 the STEP model view can be established either alone or in conjunction with the CAD view or the IFC2x Tree view. This view helps the navigation in the STEP-P21 file and tracing the modified or newly created instances. This is particularly important

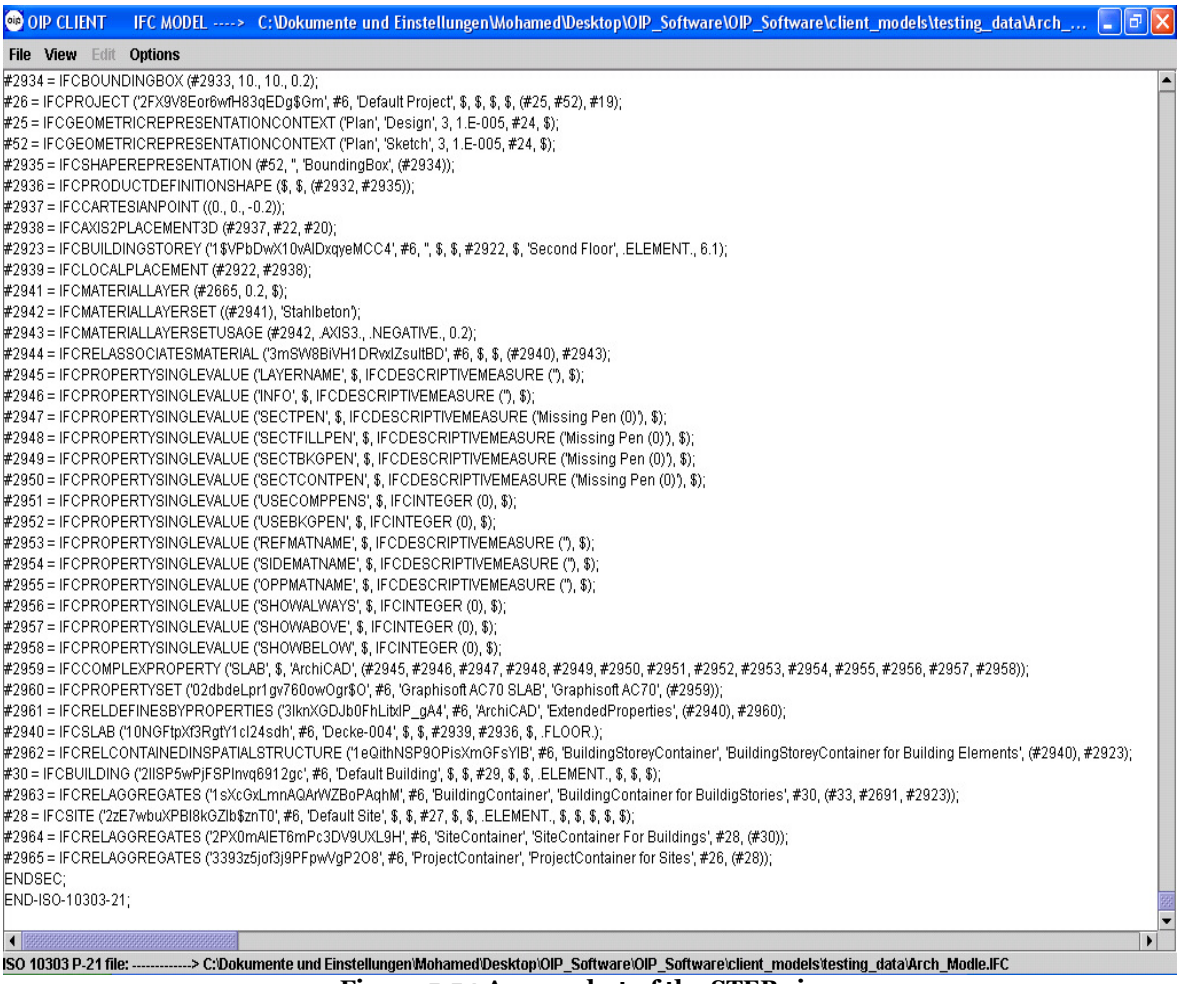


Figure 5.54 A snap shot of the STEP view

when the model undergoes some changes and the user wants to see its reflection on the STEP

model. It should be noted that the modifications can only be viewed after exporting the model, where the *STEPWriter*[14] is called to create the STEP view of the building information model.

5.5.4 Operations on the IFC Model

An important aim of this work is to enable carrying out operations needed to modify and keep the IFC model up-to-date. Among these operations are the instantiation of new property sets, property definitions, materials and classifications. Moreover, the developed software should should be able to carry out changes to the model like changing the values of the the above mentioned elements or even deleting them. This is envisaged to respond to the changes that a construction project undergoes in the design, specification and value engineering stages. Furthermore, this is considered to be the means by which the the construction product's life cycle properties could be mapped to the IFC model all over the the life cycle of the building project itself. An important goal in this process is not to cram the IFC model with all available life cycle information for each product in the project. However, the aim is to supply and support the model with up-to-date information from a continually updated and extensible data source. This implies that only needed information is mapped and instantiated in the model and that updates should always be reachable and mergable. In this way, the size of the IFC model and its exchange format (STEP ISO 10303-P21) can be minimized i.e. a fat free communication model can be reached. In other words, the model should exist in parallel to its life cycle information side by side and should be able to reference and import any piece of information according to the user 's(client's) needs.

14 It is described in detail in section 5.5.4.4 and the code is found in appendix_C/step_writer/*

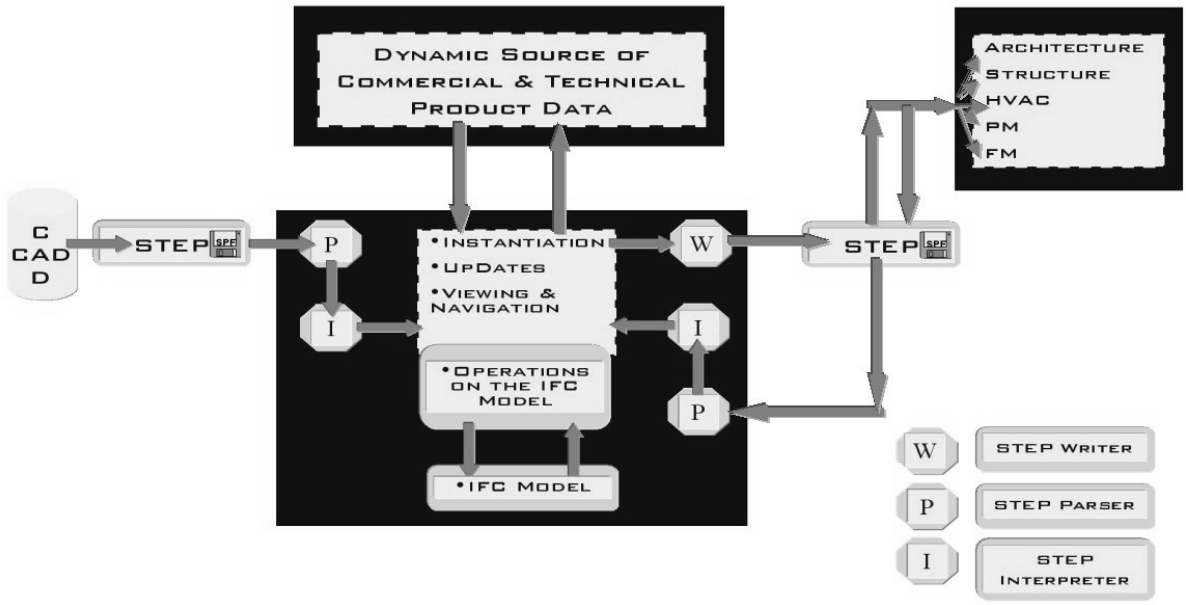


Figure 5.55 An overall view of the operations on the IFC model, (Nour et al 2005)

Figure 5.55 shows a map view of this research work, where the the whole system consists of distributed platforms that are linked with a dynamic source of commercial and technical product data. This source consists of two parts; the OIP organisation for technical information and a portal website(s) for commercial information. The user side includes the AEC-FM software applications, in addition to the software tools that are developed by the author. The latter represents the core of the system, where various types of operations can be executed on the IFC model. The operations include importing the model to a space where new data can be instantiated, updated or deleted and in the end communicated with an arbitrary number of multidisciplinary applications by interfacing with the IFC model's mapping to the STEP ISO 10303 P-21 exchange format, i.e. exporting the model.

In the meantime, products' specifications that are initiated by any AEC-FM applications (e.g. the dimensions of a product from CAD.) can be extracted and used together with the explicitly defined specifications by the user or the specifier - through the developed software tools at the client's side - in the conduction of parametric searches in portal websites.

In the end, construction product data can be mapped from a remote relational model(s) and

merged into the IFC object oriented model -at the client's side- all over the whole life cycle of the product, whenever a need for product data or updates arises. This is done by using the OIP unique identification to reach the product's data (information packs). The latter enables both the reach and richness of information about construction products and keeps the IFC building information model up-to-date, in addition to extending the limits of its information content beyond its borders.

5.5.4.1 Instantiation

In general and as shown in figure 5.56[15], before carrying out any instantiation process to a property set, property definition, a classification or even a new product, the IFC model has to be searched to find the element to which the new instance is related (IfcBuildingElement). In the scope of this work, this is done by selecting a product from either the project's tree view or the project's CAD view. Once a product is selected, then the IFC model is queried to find the objectified relationship classes instances (IfcRelxxx) that link it with other parts of the model – like a cross reference table in a relational database – and consequently, an arbitrary number of new properties, classifications, constituents or materials can be added to the product. The following is a sample example that demonstrates the instantiation process of a property set. The instantiation of classifications, materials, materials' properties and classifications follow the same algorithm.

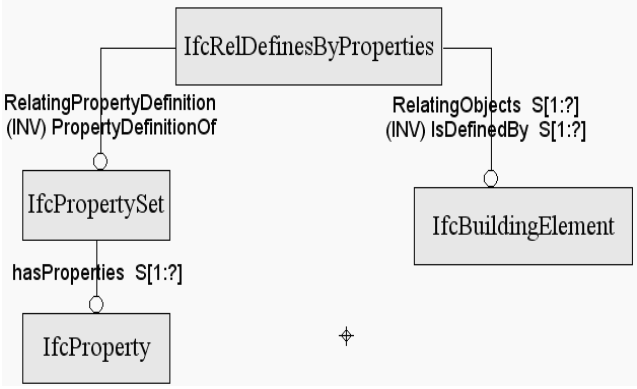


Figure 5.56 An EXPRESS-G diagram showing the relation between properties & construction products through the definition relationship, (Nour er al 2005)

As a first step for the instantiation of new property sets in the IFC Model, new Java classes have

15 Figure 5.56 is an EXPRESS-G diagram that represents an abstraction by the author that ignores inheritance of the EXPRESS entities and some of the attributes. This is done for clarification reasons and to make the diagram as simple as possible.

to be built to represent the IAI published property sets. It should be emphasised that this is one of the very strong reasons for using the IFC model[16]. The use of the published property sets like PsetDoorCommon or PsetWallCommon and so forth enables the model to overcome many of the taxonomy, ontology and language differences problems that have been met by other research projects that are discussed in detail in chapter two. And thus, every where in the world, users are able to communicate the meaning of the IAI property sets. In the meantime, this helps very much in communicating through a machine to machine language, in a sense that facilitates conduction of parametric searches.

The process of adding a new property to a product begins by searching the model and examining if the product is already linked to a property set, that this property belongs to or not. In case this property set is found, the property is simply added to the property set. In case where the property set does not exist then a new property set has to be instantiated from scratch, linked to the product through a newly created relationship instance (IfcRelxx) and the property is added to the property set. In both cases of instantiation, new instances of the constituent properties are created with the necessary parameters, added to the property set, which is linked to the *IfcBuildingElement* through the IFC kernel relations and their subtypes, as shown in figure 5.56. In the end,the new instances are added to the IFC model.

The instantiation process is done in this way due to the fact that the IfcPropertySet and IfcBuildingElement EXPRESS entities are both linked to the IFC relation by inverse attributes – as shown in figure 5.56 – that are not mapped to the STEP file. Thus, searching the relations is the only means through which the property set and the construction product could be matched together.

The PsetDoorCommon is an IAI published property set (as it can be seen from Appendix A5). It consists of eight properties (IfcPropertySingleValue) that are represented in the GUI in figure

16 The modelled IFC2x Property Sets Java classes are found in the package: step_merger.util, in Appendix C

5.57. Generally speaking, the values of the properties are extracted from the GUI. A new instance of IfcPropertySingleValue is only created and added to the model if the value of the property is instantiated by the user in the GUI.

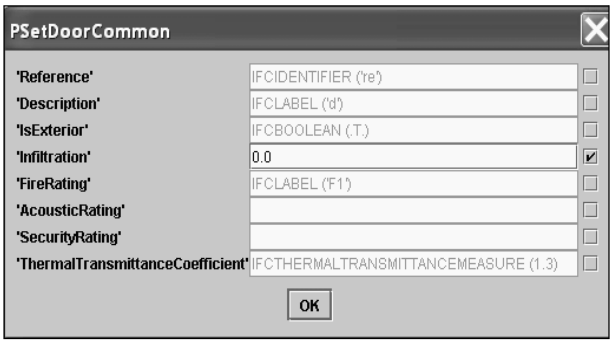


Figure 5.57 Instantiation of PsetDoorCommon

5.5.4.2 Updates

The updates to the model are carried out in the same manner like the instantiation. A product is selected from the project Tree View or from the CAD view, a query is executed in the model to find the product's attributes, property sets, classifications, materials, definitions and so forth, as shown in figure 5.43. Once the values are changed from the user interface as shown in figure 5.57, the new values replace the old ones in the IFC model. Alternatively, the values can also be explicitly changed as shown in figure 5.59, where the classification is changed from 'ISO10000' to 'ISO9000'. This change is reflected on the IFC project tree as shown in figure 5.58 and in the STEP model as follows:

```
#1050 = IFCCLASSIFICATIONNOTATIONFACET ('ISO10000');
#1060 = IFCCLASSIFICATIONNOTATION ((#1050, #1055));
#1065 = IFCRELASSOCIATESCLASSIFICATION ('OIP_0291129a7', #190, 'OIP4',
      'classification', (#650), #1060);
#1055 = IFCCLASSIFICATIONNOTATIONFACET ('DIN123');
-- #1050 will be changed to ---------------------------->
#1050 = IFCCLASSIFICATIONNOTATIONFACET ('ISO9000');
```

The value of the classification facet is replaced by the new value. The main difficulty in the above process is queering the IFC model to get hold of the classification facet that is related to the selected product through the objectified relationship class instance that links the construction product with its classifications (#1065), bearing in mind that the classification facet and the product do not have any reference to each other.

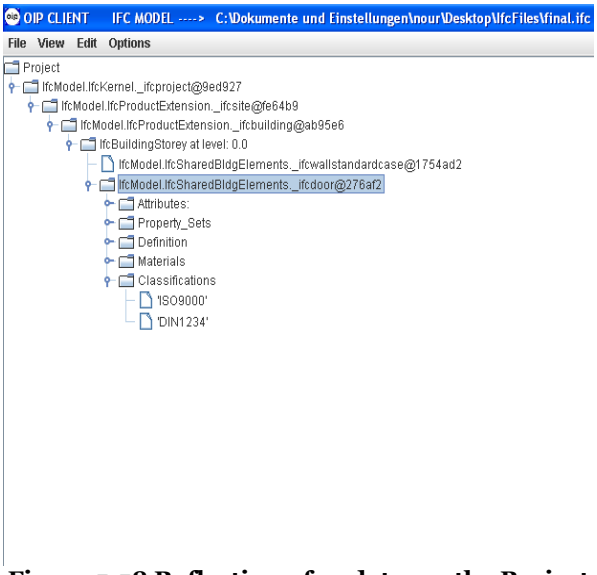


Figure 5.58 Reflection of update on the Project Tree

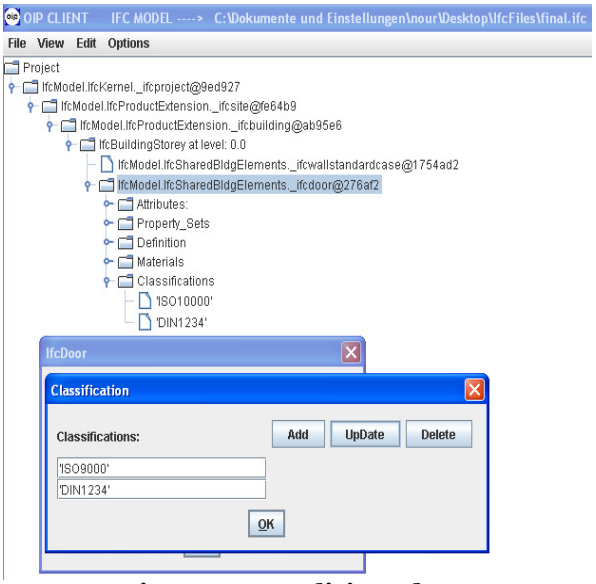


Figure 5.59 Explicit Updates

5.5.4.3 Deletion

Deletion is a special case of the Update process. It is done either by blanking the text field in the graphical user interface, as in figure 5.57 or by explicitly deleting the instantiated value as in figure 5.59. It is important here to mention that it is not only necessary to delete the references to and from the deleted object itself, but it is also very important to ensure that the object itself is deleted. If the deleted object is contained in a container class, then it should be removed. If the container class becomes empty then it should be deleted as well and finally, if there is a relation connecting the container class to an object, then the relation itself has to be deleted. All of these steps have to be done to ensure that the IFC model is not crammed with data that is not of any use, i.e. A fat free model. Otherwise the model can grow enormously in size without any need. The latter is exactly the reverse of the instantiation steps. Figure 5.56 is an EXPRESS-G diagram that shows an example of such information structure between products, relations, and the properties. Classifications, Materials, Property definitions and Property sets are all defined in the same manner. Hence, deleting any of them entails executing the above mentioned steps.

5.5.4.4 Exporting the modified STEP ISO 10303 – P21

Exporting the model in the form of a STEP ISO 10303-P21 is easily done once the model is converted to a tree structure according to its relationship references and not according to its IFC project hierarchy as it was done earlier in the visualization process. To build this tree, the Java (javax.swing.JTree) and (javax.swing.tree. DefaultMutableTreeNode) classes were used. The root elements of the tree are always the aggregation relationships that have references to different parts of the model. They act as the aggregation elements. On the other hand, elements that have no references to other elements are situated at the leaf ends of the tree.

Figure 5.60 explains an algorithm for building such a tree. The *STEPWriter*[17] iterates over the IFC model and each element's arguments, where the Java Types are mapped to STEP-P21 i.e. A reverse mapping to what the interpreter previously did. All elements are allocated new identifier numbers according to their position in the tree. From figure 5.60 we can notice that an element with an identifier #xx references another element with an identifier #yy, where xx > yy. The STEP writer iterates on the IFC model elements and their arguments and replaces the null attributes by a "$" and the references to other elements by their newly allocated identifiers. Furthermore, the same procedure is done with elements residing inside collections or container classes together with adding extra parenthesis as shown in #77 and its reference to #28 in figure 5.60.

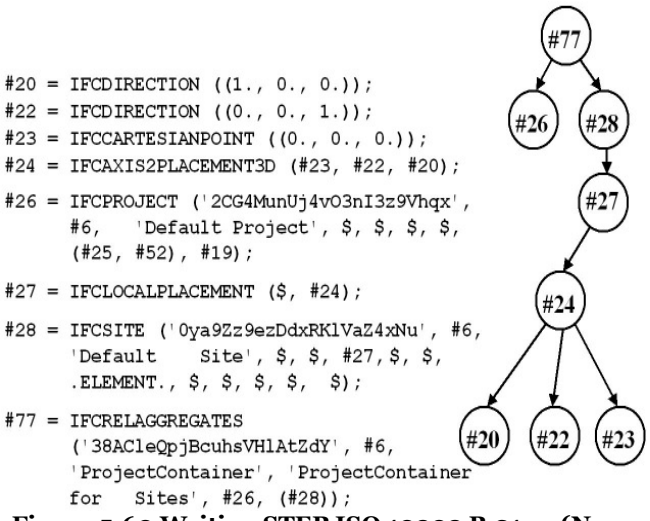


Figure 5.60 Writing STEP ISO 10303 P-21, (Nour et al 2005)

The IFC tree structure is traversed in a post order recursive manner, where each node in the tree

17 The STEPWriter class is found in Appendix "C", step_writer.Step_WriterII

is allocated an identifier number and mapped to the STEP model, after all of its children have been visited. For further details about the post order traversal methods, the reader can refer to (Wikipedia 2005).

One major problem was encountered during the building of the tree. This problem is the mutation of the nodes. In the IFC model tree a node can be referenced from more than one parent node, thus the node jumps from the old position to the new position i.e. a mutation. However, the nodes should keep their position where they are first referenced, i.e the old position; to avoid the reallocation of new line number identifiers that don't conform to referencing conventions. Hence, the major task to overcome this problem was to prevent the referencing of nodes that have already been referenced before. This was done by keeping a record of the referencing in a *HashMap* and by allowing referencing only in cases where the node has never been referenced before.

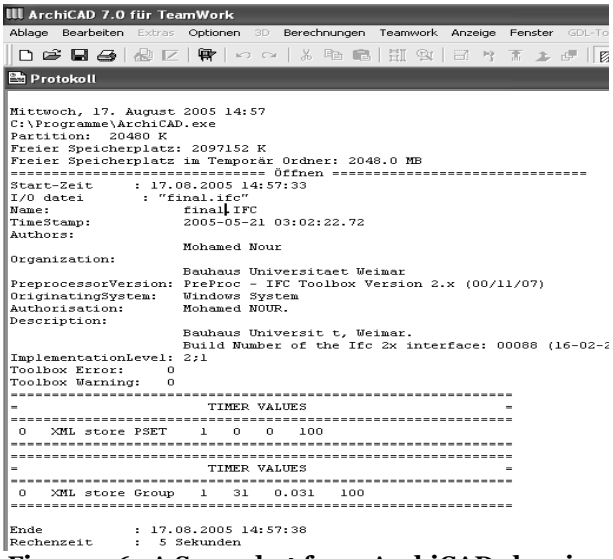


Figure 5.61 A Snap shot from ArchiCAD showing the Import results

After building the tree structure, the HEADER part of the STEP file is instantiated, and the tree is traversed in a post order recurring manner, where the leafs of the tree are iterated upon before the parents and hence given a smaller identifier line number and written first to the STEP file.

By looking at the exported STEP-P21 files from the author's software as shown in Appendix A5, we could notice that the numbering of the identifiers is incremented by five instead of one. This was done on purpose to ensure that all identifiers have been newly generated and allocated by the software. Furthermore, the latter ensures that the references between the elements are written accordingly, in addition to the correctness of the inverse mapping from the IFC Java model to the

STEP-ISO 10303-P21 model.

The exported STEP-P21 files have been fully validated by the EDM (Express Data Manager) and tested through importing them by ArchiCAD 7.0 and AutoCAD ADT (Architectural Desktop) as shown in figures 5.61 and 5.63. It has been confirmed that they were successfully imported with absolutely no errors or warnings.

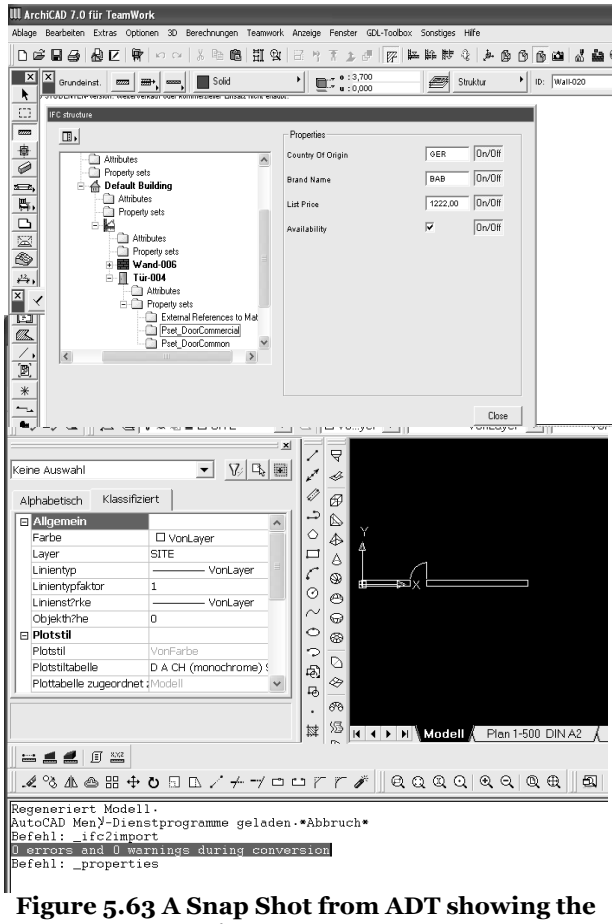


Figure 5.63 A Snap Shot from ADT showing the import results

Figure 5.62 is a snap shot from ArchiCAD 7.0 showing the newly instantiated information by the author's software. Both ArchiCAD and AutoCAD were able to import the STEP files, but unfortunately unable to re-export them without information loss. The reasons for this are discussed in detail at the end of this chapter.

5.6 Merging and Updating of Construction Product Data in the IFC model

One of the most important software tools that were developed by the author at the client side is the tool that extracts the search parameters from the products in the IFC model, performs the searching and comes back with a list of candidate products. Once a product is selected and its OIP identifier is instantiated at the *Tag* of the IFC element, then all operations become possible. Both the merging of new product information and the execution of updates depend on a drag and drop mechanism over the Internet.

5.6.1 Conduction of Parametric Searches

After the extraction of the search parameters from the CAD/IFC model – usually geometrical attributes of the element e.g. the width and hight of a door – and the explicit addition of any other parameters that are not CAD related by the user by direct instantiation, as earlier described. The software tool extracts all the technical and commercial parameters from the model (usually property sets, geometrical attributes, classifications and containment of materials or other products). A query object (code shown at "acces.database.cmds.QueryObject"in Appendix C) is formulated. The query object is divided into two parts. Part one is the commercial query which includes aspects like (brand name of the product, price range, delivery time and so forth) in a ragged array as shown in figure 5.64. Part two of the query contains all the technical aspects in a ragged array also as shown in figure 5.64. Part one of the query is first executed at the portal website and a set of compliant commercial OIP hits is returned (the set S3 at the top of figure 5.64). Those OIPs are forwarded together with the part two of the query (ragged array of technical parameters) to the OIP organisation. In the end, the intersection of both technically and commercially successful candidates (an intersection solution sets) is returned to the user to select from and instantiate the OIP identifier of the Object in the IFC model. In other words, the solution set returned to the user is the intersection of two sets; the technical and commercial sets, which satisfy the query conditions.

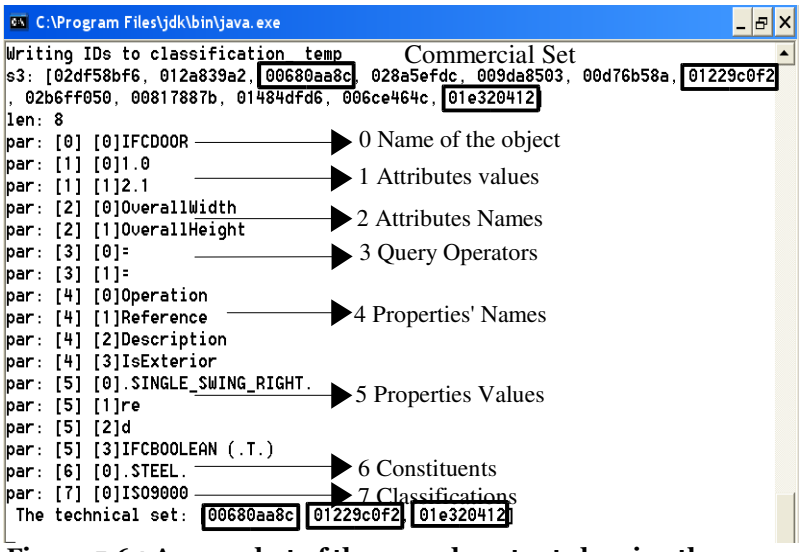


Figure 5.64 A snap shot of the console output showing the query object's ragged array of technical parameters

5.6.2 Merging Imported Product Data

Retrieving any piece of information that resides at the manufacturer's or the supplier's sides should be quite an easy task so long as there is an OIP identifier that is instantiated at the *Tag* of the OIP element. The merging process is done through a drag and drop environment over the Internet as shown in figure 5.66 and the video demonstration in appendix C (demos/UI4/Design_Model_I). There were two major problems in the design of such an interface. First was creating the transfer handler that is responsible for ensuring mapping the transferred information to the right place in the IFC model i.e. a mapping and merging process. The handler is responsible for stopping any illegal transfer of information e.g. mapping a classification to a property set or a material to a classification and so forth. The user gets a pop up message warning that the process can not be executed as the mapping is not possible between such elements. All of these aspects are regulated by the transfer handler that is found at "step_merger.ui.TreeDropTarget" in Appendix C . It is quite a long code that tries to ensure the correct mapping and merging between the source models (technical and commercial) and the target model (the IFC model), in addition to avoiding any duplication. The second problem was a technical problem concerning the transfer of data over the Internet in a drag and drop environment. This was solved by implementing both the java.awt.dnd (Drag and Drop), java.awt.datatransfer packages as well as the RMI (Remote Method Invocation) package at the same time. Any transferred object is wrapped inside a javax.swing.tree.DefualtMutableTreeNode that is wrapped inside a step_meger.ui.TransferebaleTreeNode (a class developed by the author) as shown in figure 5.65. The readers who are interested in the technicalities of the solution can refer to the UML diagrams together in Appendix B and to the code in the package "step_merger.ui" in Appendix C.

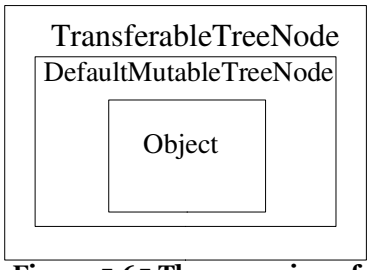


Figure 5.65 The wrapping of transferred objects over the Internet

Figure 5.66 shows a GUI that contains three tree views. The one at the top left represents the

construction product's technical information at the OIP organisation. The one at the top right represents the commercial properties of the product at he portal web site. The tree at the bottom represents the project tree of the IFC model at the client's side. The mapping takes place at two levels. The first level is the GUI level, where nodes are mapped and added to the correct place in the tree as a result of a successful merging process (if the merging is allowed according to the mapping rules, that are defined in the transfer handler). All the above is demonstrated by video in appendix C (demos /UI4/ Design_Model_I).

The second level is the IFC model that resides behind the GUI at the client side. At this level, before allowing any merging process to happen, the IFC model has to be checked to avoid duplication of merged elements. Moreover, if the mapped element is not added to a pre-existing container and the needed relations exist as well, then all necessary relations and container classes have to be created from scratch (a new instantiation process as earlier described).

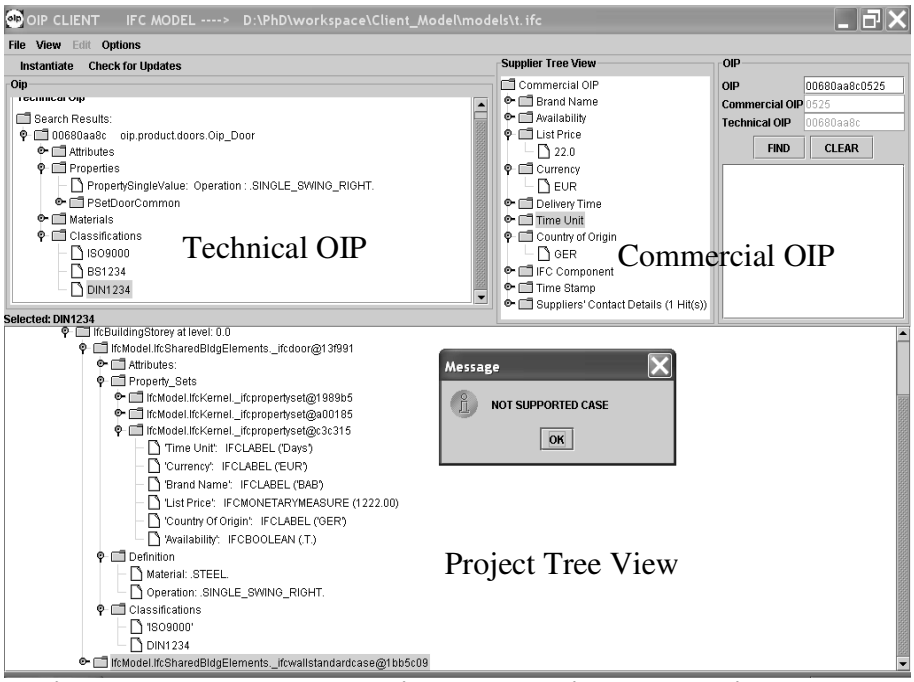


Figure 5.66 The GUI for merging and updating construction product information to the IFC model

5.6.3 Updating Product Information

Checks for updates of commercial information about a construction product could be executed once an OIP identifier has been instantiated inside the object (at the Tag attribute of the IFCELEMENT entity). The Tag attribute contains both the OIP identifier as well as a time stamp

of the last update that has taken place on the commercial properties.

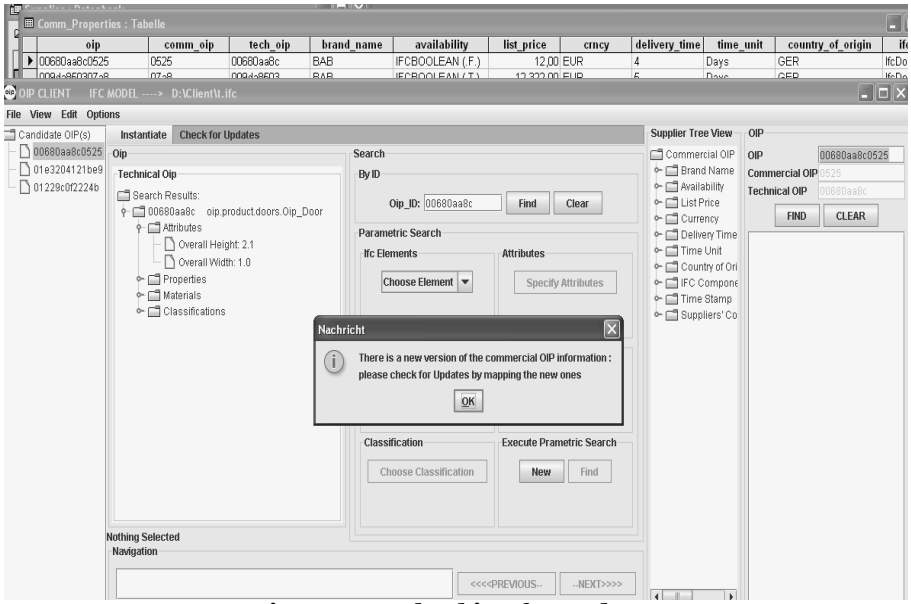


Figure 5.67 Checking for updates

When a check for an update is executed by the user, the time stamp at the portal database and the one at the object's tag inside the IFC model are compared. If a more recent time stamp is discovered, then the software attracts the user's attention to the existence of updated information that should be changed in the building information model, as shown in figure 5.67 and in the video demonstration in appendix C (demos/UI4/Updates).

5.7 Work flow Management Aspects

The IFC model is mostly used for the transfer of information from one software to another. There is always a gray area between software applications that enables the information to be mapped from one software application to the other. However, there are more often than not functionalities that are supported by one software and not by the others. This often results in an inevitable information loss; especially, when the model is saved by an application that imports an IFC model and does not support the functionalities of the software that originally produced it. Further more, some times it has nothing to do with functionalities, the software maps its information content to IFC and ignores the information that was originally imported within the model. This is exactly the case that the author encountered when the IFC model was instantiated by product data and re-imported by CAD software (ArchiCAD 7.0, Students version and ADT 3.3) the software could show the newly instantiated information as shown in figure 5.62 with the PsetDoorCommercial property set, but when asked to re-export the model, the software mapped

its objects to a STEP file and took no care of the extra information in the model. Hence, the IFC model looses its advantage as an independent non proprietary building information model that is capable of transmitting multidisciplinary AEC information if it is used in such a manner. Consequently, either the way of use has to be changed or the software developers have to change their strategies. Moreover, it has been proved now that the scenario of the incremental development of a single building information model that has been presented by the IAI since 1996 has not been achieved.

Researchers like (Kiviniemi et al 2005a) and (Haymaker et al 2003) argue that the existing software products can not support all features of the IFC model. Furthermore, they emphasis the fact that there are no potential customers for applications that cover all different information needs due to the fragmented nature of the AEC industry. Hence, they believe that for a building project, there should be several instantiated models where the shared information should be linked together across the models, i.e. without merging the models together in one model. The latter might be a way of use that can overcome the above mentioned work flow problems.

At the time of writing this thesis, there are three major trials to solve this problem by developing IFC model servers since the year 2001. These trials are (ImSvr 2001), (WebSTEP 2003) and (EPM 2003). All of these models provide partial model information exchange. However, the concept of a multi-model environment has not been tested in real projects. (Kiviniemi et al 2005b). It should be mentioned that the author's software is capable of without information loss.

5.8 Summary & Conclusions

The aim of this chapter was to present a proof of concept to the idea of linking technical and commercial construction product life-cycle data to the IFC model in a trial to help providing Building Information Models with up-to-date product data all over the life-cycle of the building.

The work in this chapter simulated a distributed network application that represents all the

parties involved in the value chain of the construction product. Five main graphical user interfaces were built on top of the application for facilitating the updating, transfer and merging of product data to the IFC model.

A number of software tools have been developed at the client's side to enable the manipulation and visualization of the information in the IFC model. Among these tools are a STEP-ISO 10303-P21 parser, an IFC2x Interpreter, an IFC2x project tree viewer, a CAD viewer and a STEP code viewer (where the changes on the model can be monitored). As a prerequisite for the development of such tools, the IFC EXPRESS entities had to be mapped to Java classes using a mix of early and late binding approaches.

The development of such tools enables operations like the instantiation of new elements, updates, deletion and exporting the modified models to take place. This is considered by all means to be the key enabler for the retrieval of product data, either through the OIP identifier or by conduction of parametric searches for construction product over the Internet. Moreover, they enable merging new data and updating old information in the IFC model. It is worth mentioning that the process of updating commercial product data was achieved by using a versioning system that depends on a time stamp that indicates the availability of updates. Such functionalities were made available through the graphical user interface at the client's side by using both the DnD (Drag and Drop) environment and the RMI (Remote Method Invocation) at the same time.

On the other hand, both the roles of the OIP organisation and the portal website were represented by a distributed network application that is built on top of relational databases (for the persistence of data). A major problem was the shifting from the persistent relational model to the run-time object oriented model of such applications. Nevertheless, this problem was solved by building the objects at run-time by using SQL queries.

Moreover, the role of the manufacturer of the construction product was involved in the

distributed network application through a simple graphical user interface that enabled the registration of the product's technical data at the OIP organization, in addition to the allocation of an OIP technical identifier.

Finally, the chapter ended with a work flow management remark. It was noticed that the commercial applications like ArchiCAD 7.0 from Graphisoft and ADT (Architectural Desktop) from Autodesk could successfully import the IFC model that is exported from the author's software and they could display some of the newly instantiated data that is not CAD related. However, when it was required to export the model, an inevitable loss of information was encountered. Reasons that might be standing behind such an information loss were mentioned together with the provision of some guidelines that might be able to help rectify such problems. This aspect might be one of the recommendations for further research in this field.

Chapter 6

Conclusions and recommendations for further research

6.1 Conclusions

This thesis established a flexible and dynamic building information model with the ability to access, query and update information about construction products. Moreover, it tried to establish a link between products in the building information model from one side and their information at the manufacturers' and suppliers' data repositories from the other side. This is envisaged to provide open access to the manufacturer's and supplier's product information by enabling both product parameter and global unique identification.

By viewing the literature and the state-of-the-art of electronic product catalogues, it was found that the majority of commercial product catalogue vendors still depend on a free text HTML or PDF information content that is searched by keywords. The latter is not reusable by electronic means for design purposes and is not able to be mapped and merged to building information models. At the CAD vendors level, it has been found that they do not support parametric searches, where it is of paramount importance not only to hand-specify the product's parameters, but also to extract the parameters from the existing building information model. Moreover, most trials were proprietary commercial developments that resulted in the incapability of transferring data to a foreign environment without information loss. Furthermore, the freedom to structure data about product properties without following any standards leads more often than not to the inability to communicate meanings. Meanwhile, the majority of independent research projects were more focused on building new taxonomies and ontologies that can be implemented by XML for communication of meanings. They are more often than not depending on a central database

that can be accessed over the Internet.

By investigating the life-cycle of construction products, together with their value and supply chains, it was found that there is not only a need for life-cycle information, but also for information over the whole life-cycle of the product. Meanwhile, from a commercial point of view, it was also found that suppliers usually sell products from the same manufacturer, but under different brand names. The role of the brand name in the marketing strategies was investigated and emphasized as a major player in marketing strategies. Also the role of middlemen was emphasized even for transactions that take place over the Internet. Furthermore, the fact that construction products have the peculiarity that they can be partially or wholly fabricated on site had to be reflected on the design of any information system that tries to address the construction product's value chain.

The work has also concluded that the idea of construction product global unique identification together with the support of other types of searches and especially the parametric searches might help in changing the current status. Furthermore, the IFC model with its non-proprietary characteristics, its multidisciplinary nature and published property sets is a considerable candidate for any prototype development.

Returning to the main point concerning the suggested solution concept, the work has introduced the OIP (Object Information Pack) that can be used as a permanent and dynamic source of data to Building Information Models. The OIP is not just a global unique identifier; it is an information data structure. It consists of a three layers hierarchy that is reflected in its database structure which is managed by a group of relations that reside in the OIP kernel. The design of the OIP identifier itself and the distribution of the products data among several parties and databases (technical data at the OIP organisation and commercial data at suppliers and portal websites) is considered to be a key change to the use of the single central database, as it has been done in previous research projects. The solution concept in this work was developed from a close

observation and analysis to the construction products' value chain and the peculiarity of the construction industry itself.

It has also been found that the OIP concept alone is not enough to bridge the gap between the manufacturer's and the supplier's data at one end and the client at the other end. A set of software tools had to be developed to enable the whole concept to be implemented. At the time of writing this thesis, there is no one group of software applications that are integrated together and capable of proving the concept of this work. Hence, these tools had to be developed by the author. These tools have the following functionalities:

- Parsing STEP ISO 10303-P21 files.
- Interpreting the parsed data to the IFC2x Java Classes.
- Mapping and merging of product data to the IFC model.
- Performing a whole range of instantiation, deletion and update processes.
- Explicit Definition of query parameters by the user.
- Extraction of query parameters from the CAD/IFC model.
- Conduction of parametric searches, providing different types of visualisations of the IFC model and exporting the modified IFC model as a STEP-P21 file.

These tools played an important role in proving the concept behind this work. Moreover, they have been designed to be able to be used by other researches that are dealing with the IFC2x model in other aspects. They are just simple tools that open a window of opportunities to other applications to integrate with the IFC model.

Finally, the roles of the OIP organization, the portal websites and the manufacturers have also been simulated by a distributed network application. Graphical user interfaces were built on top of all tools in order to demonstrate the results and to provide a clear proof of concept.

At the end of this work, the author would like to emphasis that the taking over of such a *Business*

Process Re-engineering (BPR) in the industry practice is not free of problems and barriers. It is well known from the literature of organizational cultures and psychology that users are always reluctant to the implementation of revolutionary systems that change the traditional ways of doing things, (even if it results in a more optimisation and efforts saving on the long run). However, the change of current practice can still be achieved by the commitment of the top management of major market players together with convincing users with the advantages of the new systems and making them feel it on the ground.

6.2 Review of chapters

Chapter 2 responds to the first objective of the thesis (chapter one, section 1.2.2). It is a review of the literature of linking construction product data to building information models. It concludes that most of the commercial product catalogue vendors are oriented towards text based searches. Moreover, many research projects are designed to work around a central database, where data transfer and communication of meaning is a main research point that is out of the scope of this work. On the other hand, many projects have tried to link product data to CAD environments. However, it was found that the product selection process is still confined to navigating web pages at the hosting website. Furthermore, the majority of such CAD integrated systems are proprietary developments that result in an inevitable information loss by shifting to other CAD environments.

Chapter 3 responds to the second and third objectives of the thesis (chapter one, section 1.2.2). It includes an analysis of the construction product's value chain and its marketing strategies. It identifies the key barriers for the lack of integration between construction product data and Building Information Models. It puts forward a set of guidelines for any concept of a solution development that wants to benefit from the literature and state-of-the-art analysis that has been made in the previous chapters.

Chapter 4 responds to objective number four of the thesis. It provides a concept of a solution that implements the guidelines that were identified in chapter three. It provides a definition of the concept supported by examples and scenarios of use.

Chapter 5 or part II of the thesis responds to objectives number five, six and seven (chapter one, section 1.2.2). It proves the suggested solution concept in chapter four. It identified the need to particular software tools that are essential for proving the solution concept together with the needed programming technologies that have to be learned and used. Example of such technologies are the Java Compiler Compiler technology for parsing the STEP-ISO 10303-P21 files, the JAVA 2D package for visualization, Java RMI and sockets for communication EXPRESS ,STEP and so forth. An open distributed software platform that simulates and validates the solution's concept has been tested with real life data models.

6.3 Recommendations for further studies and concept development

6.3.1 Further studies

It has been proved that a construction product can be linked all over its whole life-cycle to its data sources. It is hoped that this would open a window of opportunities for multidisciplinary AEC-FM software applications to benefit from such flexibility that allows both the richness and reach of construction product information. Hence, any further use of the building information model in a manner that makes use of its ability to get hold of external up-to-date construction products information is considered to be an emphasise to the success of this research work.

Among such applications are the conduction of virtual experiments and simulations, not only to select construction products on the basis of performance criteria, but also in many other fields such as: The prediction of the structural behaviour of buildings and materials under different conditions e.g. earthquakes, energy performance, in computational fluid dynamics (CFDs) and ventilation or even the acoustical design and so forth.

In addition, the concept could be applied to the area of collaborative work. Different AEC-FM disciplines who work on the same building information model(s), try to achieve the consistency of the model and ensure its validity by establishing consistent versions of the model. If the external links from the model to the products' data are valid, up-to-date and consistent with the design versions, then a reliable model can be achieved.

6.3.2 Concept development

The work in this thesis has only implemented the product part of the OIP concept. The OIP model is designed in an extensible manner that enables the addition and implementation of new aspects such as construction services and activities. Nevertheless, this necessitates that the model should not only include product modelling but also process modelling aspects as well. These activities or processes can then be linked to the project planning processes, where the allocation of resources, time scheduling and site layout planning are of great need to the electronic transfer of such information.

Another development could be achieved in the area of construction products and materials resides in the potentiality of improving their logistics by using the OIP unique identifier as a part of a product instance identifier (as a serial number or a bar code). It can facilitate the tracing and monitoring of the product or material throughout the value chain and its whole life-cycle. This might be able to play an important role in Material Requirement Planning (MRP) of construction products, where scheduling, site layout planning and inventory could be planned accordingly.

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Appendix A1: *An Example of a STEP ISO 10303-P21 file*

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (
('Sample NURBS geometry for a Boeing 707', /* description */
'for the Common STEP Tasks tutorial'),'1'); /* impl level */
FILE_NAME ('ap203_database', /* name */
'2004-05-18T14:18:59-04:00', /* timestamp */
('Nour Mohamed'), /* author */
('STEP Tools Inc.', /* organization */
'Rensselaer Technology Park',
'Troy, New York 12180',
'info@steptools.com'),
'ST-DEVELOPER v1.4', /* preprocessor */
'', /* originating system */
''); /* authorization */
FILE_SCHEMA (('IFC_2x')); /* schema */
ENDSEC;
DATA;
#1 = IFCORGANIZATION ('GS', 'Graphisoft', 'Graphisoft', $, $);
#3 = IFCPERSON ($, 'Undefined', $, $, $, $, $, $);
#4 = IFCORGANIZATION ($, 'OrganizationName', $, $, $);
#5 = IFCPERSONANDORGANIZATION (#3, #4, $);

#7 = IFCSIUNIT (*, .LENGTHUNIT., $, .METRE.);
#8 = IFCSIUNIT (*, .AREAUNIT., $, .SQUARE_METRE.);
#9 = IFCSIUNIT (*, .VOLUMEUNIT., $, .CUBIC_METRE.);
#10 = IFCSIUNIT (*, .PLANEANGLEUNIT., $, .RADIAN.);
#11 = IFCMEASUREWITHUNIT (IFCPOSITIVELENGTHMEASURE (57.29577951308232), #10);
#12 = IFCDIMENSIONALEXPONENTS (0, 0, 0, 0, 0, 0, 0);
#13 = IFCCONVERSIONBASEDUNIT (#12, .PLANEANGLEUNIT., 'DEGREE', #11);
#14 = IFCSIUNIT (*, .SOLIDANGLEUNIT., $, .STERADIAN.);
#15 = IFCSIUNIT (*, .MASSUNIT., $, .GRAM.);
#16 = IFCSIUNIT (*, .TIMEUNIT., $, .SECOND.);
#17 = IFCSIUNIT (*, .THERMODYNAMICTEMPERATUREUNIT., $, .DEGREE_CELSIUS.);
#18 = IFCSIUNIT (*, .LUMINOUSINTENSITYUNIT., $, .LUMEN.);
#19 = IFCUNITASSIGNMENT ((#7, #8, #9, #13, #14, #15, #16, #17, #18));

#21 = IFCDIRECTION ((0., 1., 0.));
#29 = IFCLOCALPLACEMENT (#27, #24);
#27 = IFCLOCALPLACEMENT ($, #24);
#24 = IFCAXIS2PLACEMENT3D (#23, #22, #20);
#23 = IFCCARTESIANPOINT ((0., 0., 0.));
#22 = IFCDIRECTION ((0., 0., 1.));
#20 = IFCDIRECTION ((1., 0., 0.));
#31 = IFCAXIS2PLACEMENT3D (#23, #22, #20);
#32 = IFCLOCALPLACEMENT (#29, #31);
#6 = IFCOWNERHISTORY (#5, #2, $, .NOCHANGE., $, $, $, 1112701816);
#2 = IFCAPPLICATION (#1, '7.0', 'ArchiCAD 7.0', 'ArchiCAD');

#34 = IFCMATERIAL ('Gips');
#35 = IFCMATERIALLAYER (#34, 0.365, $);
#36 = IFCMATERIALLAYERSET ((#35), 'Gips');
#37 = IFCMATERIALLAYERSETUSAGE (#36, .AXIS2., .POSITIVE., 0.);

#38 = IFCCARTESIANPOINT ((0., 0.));
#39 = IFCCARTESIANPOINT ((6., 0.));
#40 = IFCPOLYLINE ((#38, #39));
#41 = IFCSHAPEREPRESENTATION (#25, 'Axis', 'Curve2D', (#40));
#42 = IFCCARTESIANPOINT ((0., 0.));
#43 = IFCCARTESIANPOINT ((6., 0.));
#44 = IFCCARTESIANPOINT ((6., 0.365));
#45 = IFCCARTESIANPOINT ((-6.162975822039155E-033, 0.365));
#46 = IFCPOLYLINE ((#42, #43, #44, #45, #42));
#47 = IFCARBITRARYCLOSEDPROFILEDEF (.AREA., $, #46);
#48 = IFCAXIS2PLACEMENT3D (#23, #22, #20);
```

HEADER Section

Section 1: The definition of Units in the IFC Project Instant according to the SI System

Section 2: The definition of the wall's material

```
#49 = IFCEXTRUDEDAREASOLID (#47, #48, #22, 2.7);
#50 = IFCSHAPEREPRESENTATION (#25, 'Body', 'SweptSolid', (#49));
#51 = IFCBOUNDINGBOX (#23, 6., 0.365, 2.7);
#25 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Design', 3, 1.E-005, #24, $);
#52 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Sketch', 3, 1.E-005, #24, $);
#26 = IFCPROJECT ('2CG4MunUj4vO3nI3z9Vhqx', #6, 'Default Project', $, $, $, $, (#25, #52),
#19);
#53 = IFCSHAPEREPRESENTATION (#52, '', 'BoundingBox', (#51));
#54 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#41, #50, #53));
#55 = IFCAXIS2PLACEMENT3D (#23, #22, #20);
#33 = IFCBUILDINGSTOREY ('2uKnZK72LCAxbjZFD7EaQm', #6, '', $, $, #32, $, '', .ELEMENT.,
0.);
#56 = IFCLOCALPLACEMENT (#32, #55);
#58 = IFCRELASSOCIATESMATERIAL ('32B1UlqNz4fxYalcsSKrzq', #6, $, $, (#57), #37);
#57 = IFCWALLSTANDARDCASE ('1juGXWoCL1auasdHNXsRHo', #6, 'Wand-006', $, $, #56,
#54, $);
#74 = IFCRELCONTAINEDINSPATIALSTRUCTURE ('3xPT1B2IL9V995T1G5R66w', #6,
'BuildingStoreyContainer', 'BuildingStoreyContainer for Building Elements', (#57), #33);
#30 = IFCBUILDING ('3IExBBu7L0OO1zvCmAsCzz', #6, 'Default Building', $, $, #29, $, $, .
ELEMENT., $, $, $);
#75 = IFCRELAGGREGATES ('136BXTXr556eyQ5BRc142a', #6, 'BuildingContainer',
'BuildingContainer for BuildigStories', #30, (#33));
#28 = IFCSITE ('0ya9Zz9ezDdxRKlVaZ4xNu', #6, 'Default Site', $, $, #27,
 $, $, .ELEMENT., $, $, $, $, $);
#76 = IFCRELAGGREGATES ('0OHMZ0ltz7eP2I0RZ_rRGK', #6, 'SiteContainer',
'SiteContainer For Buildings', #28, (#30));
#77 = IFCRELAGGREGATES ('38ACleQpjBcuhsVHlAtZdY', #6, 'ProjectContainer'
, 'ProjectContainer for Sites', #26, (#28));

ENDSEC;
END-ISO-10303-21;
```

Section 3: Relating the project constituents

Appendix A2: A jjdoc output of the STEP_Parser.jj grammar file for the NON-TERMIANLS.

```
Start          ::=    stepHeader
stepHeader     ::=    ( <ISOSTEP> <IDENTIFIER> <EOC> ( <IDENTIFIER>
                      <OPEN_B> argList          <CLOSE_B> <EOC> )+  <ENDSEC>
                      <DATA> )+ ifcList  ( <ENDSEC><END_ISO_STEP> )+
ifcList        ::=    ( ifcElement )*
ifcElement     ::=    <Line_Nr> <EQUALS> <IDENTIFIER> <OPEN_B> argList
                      <CLOSE_B> <EOC>
argList        ::=    ( arg )*
arg            ::=    <IDENTIFIER>
                      |    <WILD>        // for parsing any user defined String
                      |    <Line_Nr>     // identifier of the element (# 9 digits)
                      |    ","           //to separate between attribute values
                      |    <ASTRISK>     //attributes that are re-defined in sub-classes
                      |    <IFC_VALUE>
                      |    <IFC_UNIT>
                      |    ( "+" )? numLiteral
                      |    ( "-" )? numLiteral
                      |    "(" argList ")"
numLiteral     ::=
                      <INTEGER_LITERAL>
                      |    <FLOATING_POINT_LITERAL>
```

Appendix A3: IAI Definition of the the PsetDoorCommon

Name	Property Type	Data Type	Definition
Reference	IfcPropertySingleValue	IfcIdentifier	User defined reference for this door type in this project (e.g. type 'D-1')
Description	IfcPropertySingleValue	IfcString	Specific description for this type of door within this project.
IsExterior	IfcPropertySingleValue	IfcBoolean	Indication whether the door type is designed for use in exterior walls (TRUE) or not (FALSE)
Infiltration	IfcPropertySingleValue	IfcReal / UserDefined	Infiltration flow rate of outside air for the filler object based on the area of the filler object at a pressure level of 50 Pascals. It shall be used, if the length of all joints in unknown. The usual unit (if pressure is taken into consideration) is m3/(hPa2/3). The following translations apply: G: Fugendurchlassigkeit
ThermalTransmittanceCoefficient	IfcPropertySingleValue	IfcThermalTransmittanceMeasure / ThermalTransmittanceUnit	Overall thermal transmittance coefficient (U-Value) of the composite materials used by the filler object. It includes internal and external surface coefficient. The usual unit is W/m2K. The following translations apply: G: Gesamtwarmedurchgangskoeffizient
FireRating	IfcPropertySingleValue	IfcString	Fire rating of complete door assembly. Given according to the national fire safety classification.
AcousticRating	IfcPropertySingleValue	IfcString	Rating for acoustic transmisivity (Sound Transference Factor =STF) for the complete door assembly.
SecurityRating	IfcPropertySingleValue	IfcString	Index based rating system indicating security level.

Appendix A4: The Java Code for the Property Set PsetDoorCommon

In section one of the code, the owner history entity (IfcOwnerHistory) is sought from the IFC2x model, as it is needed for the instantiation of the model. In section two, the values of the properties are extracted from the graphical user interface, as shown in figure 5.57. A new instance of IfcPropertySingleValue is only created and added to the model if the value of the property is instantiated by the user from the GUI. Moreover, in this case, a reference to the property is added in the property set (a HashSet), as shown in section three of the code.

```
package step_merger.util;

public class PSetDoorCommon
{
      _ifcpropertysinglevalue p1=null;
      _ifcpropertysinglevalue p2=null;
      _ifcpropertysinglevalue p3=null;
      _ifcpropertysinglevalue p4=null;
      _ifcpropertysinglevalue p5=null;
      _ifcpropertysinglevalue p6=null;
      _ifcpropertysinglevalue p7=null;
      _ifcpropertysinglevalue p8=null;
      public _ifcpropertysinglevalue[] array={p1,p2,p3,p4,p5,p6,p7,p8};
      public _ifcpropertyset prop_set=null;
      public String REF=null;    public String DESC=null;
      public String IsExterior=null;   public String INF=null;
      public String FIRE=null;  public String ACC=null;
      public String SEC=null;    public String Thermal=null;
      public String[] values;
      public String[] names={ "REFERENCE", "DESCRIPTION", "IsExterior",
      "INFILTRATION", "FIRE", "ACCOUSTIC", "SECURITY", "Thermal"};
      SDAI select=null;
      SDAI[] elements =null;
      public HashSet prts=null;
      _ifcownerhistory hist=null;
      public PsetDoorCommon(SDAI[] _w, SDAI _select)
      {     elements=_w;
      //Section I getting the ownerhistory (needed for the instatiation)
            for (int i=0; i< elements .length  ; i++)
            {
                  if (elements  [i] instanceof _ifcownerhistory)
                  {
                        hist=(_ifcownerhistory)elements  [i];
                  }
            }
            this.select =_select;
      } // Section II Setting the vlaues obtained from the GUI
      public void  setValues()
      {
               REF=values[0];
               DESC=values[1];
               IsExterior=values[2];
               INF=values[3];
               FIRE=values[4];
               ACC=values[5];
               SEC=values[6];
               Thermal=values[7];
            if (REF != null)
            {
                  Object[] o1=
                  {"#"+w.m.max_lnr++, "IFCPROPERTYSINGLEVALUE",
```

Section One

Section Two

```
                "'Reference'", "'generatedId'", REF.trim(),null};
                p1=new _ifcpropertysinglevalue();
                p1.setAttributes(o1, new Ln_Map());
        }
        if (DESC != null)
        {
                Object[] o2=
                        {"#"+w.m.max_lnr++,"IFCPROPERTYSINGLEVALUE",
                                "'Description'", "'Specific description for   this type of
                door'",
                DESC.trim(), null};
                p2=new _ifcpropertysinglevalue();
                p2.setAttributes(o2,new Ln_Map());
        }
        if (IsExterior != null)
        {
                Object[] o3=
                        {"#"+w.m.max_lnr++, "IFCPROPERTYSINGLEVALUE",
                                "'IsExterior'","... " ,this.IsExterior !      =null ?
                                        IsExterior.trim(): null , null};
                p3=new _ifcpropertysinglevalue();
                p3.setAttributes(o3, new Ln_Map());
        }
        if (INF != null)
        {
                Object[] o4= {"#"+w.m.max_lnr++,
                        "IFCPROPERTYSINGLEVALUE", "... " , INF.trim(),       null};
                p4=new  _ifcpropertysinglevalue();
                p4.setAttributes(o4, new Ln_Map());
        }
        if (Thermal != null)
        {       Object[] o5={"#"+w.m.max_lnr++,
                        "IFCPROPERTYSINGLEVALUE", "...","
                'THERM'",this.Thermal==null? null :this.Thermal.trim
                (),null};
                p5=new _ifcpropertysinglevalue();
                p5.setAttributes(o5, new Ln_Map());
        }
        if (FIRE != null)
        {
                Object[] o6={"#"+w.m.max_lnr++,
                        "IFCPROPERTYSINGLEVALUE", "'FireRating'", "..." ,
                FIRE.trim(),null};
                p6=new _ifcpropertysinglevalue();
                p6.setAttributes(o6, new Ln_Map());
        }
        if (ACC != null)
        {
                Object[] o7={"#"+w.m.max_lnr++,
                        "IFCPROPERTYSINGLEVALUE", "..." , ACC.trim(),        null};
                p7=new _ifcpropertysinglevalue();
                p7.setAttributes(o7, new Ln_Map());
        }
        if (SEC != null)
        {
                Object[] o8={"#"+w.m.max_lnr++,
                        "IFCPROPERTYSINGLEVALUE", "'SecurityRating'"," ...   " ,
                        SEC.trim(),null};
                p8=new _ifcpropertysinglevalue();
                p8.setAttributes(o8, new Ln_Map());
        }
}
public void write() {  // adding the properties to the model
        ArrayList mylist= new ArrayList();
        for (int i=0; i< elements .length ; i++){
                mylist.add(elements [i]);
        }
        // adding the single properties to both the IfcElements list
                // and the properties set.
```

Section Two

Section Three

```
            prts= new HashSet();
            if (p1 != null) {mylist.add(p1);prts.add(p1);}
            if (p2 !=    null) {mylist.add(p2);prts.add(p2);}
            if (p3 != null) {mylist.add(p3);prts.add(p3);}
            if (p4 != null) {mylist.add(p4);prts.add(p4);}
            if (p5 != null) {mylist.add(p5);prts.add(p5);}
            if (p6 != null) {mylist.add(p6);prts.add(p6);}
            if (p7 != null) {mylist.add(p7);prts.add(p7);}

            if (p8 !=    null) {mylist.add(p8);prts.add(p8);}
            ArrayList b= new ArrayList(prts);
            creatPropertySet(select, prts.toArray() , null,
                  "Pset_DoorCommon");
      }
}
```

Section Three

Appendix A5: An example of an exported STEP-P21 file from the author's software

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION (('Bauhaus Universität, Weimar.','Build Number of the Ifc 2x interface:
00088 (16-02-2003)'), '2;1');
FILE_NAME ('prova1.IFC', '2005-06-27 21:58:11.553' ,('Mohamed Nour'), ('Bauhaus
Universitaet Weimar'), 'PreProc - IFC Toolbox Version 2.x (00/11/07)', 'Windows
System','Mohamed NOUR.');
FILE_SCHEMA (('IFC2X_FINAL'));
ENDSEC;

DATA;

#5 = IFCSIUNIT (*, .LENGTHUNIT., $, .METRE.);
#10 = IFCSIUNIT (*, .AREAUNIT., $, .SQUARE_METRE.);
#15 = IFCSIUNIT (*, .VOLUMEUNIT., $, .CUBIC_METRE.);
#20 = IFCDIMENSIONALEXPONENTS (0, 0, 0, 0, 0, 0, 0);
#25 = IFCSIUNIT (*, .PLANEANGLEUNIT., $, .RADIAN.);
#30 = IFCMEASUREWITHUNIT (IFCPOSITIVELENGTHMEASURE (57.29577951308232), #25);
#35 = IFCCONVERSIONBASEDUNIT (#20, .PLANEANGLEUNIT., 'DEGREE', #30);
#40 = IFCSIUNIT (*, .SOLIDANGLEUNIT., $, .STERADIAN.);
#45 = IFCSIUNIT (*, .MASSUNIT., $, .GRAM.);
#50 = IFCSIUNIT (*, .TIMEUNIT., $, .SECOND.);
#55 = IFCSIUNIT (*, .THERMODYNAMICTEMPERATUREUNIT., $, .DEGREE_CELSIUS.);
#60 = IFCSIUNIT (*, .LUMINOUSINTENSITYUNIT., $, .LUMEN.);
#65 = IFCMATERIAL ('Gips');
#70 = IFCMATERIALLAYER (#65, 0.365, $);
#75 = IFCCARTESIANPOINT ((0.0, 0.0));
#80 = IFCCARTESIANPOINT ((10.10120319042872, 0.0));
#85 = IFCPOLYLINE ((#75, #80));
#95 = IFCSHAPEREPRESENTATION (#90, 'Axis', 'Curve2D', (#85));
#100 = IFCCARTESIANPOINT ((0.0, 0.0));
#105 = IFCCARTESIANPOINT ((10.10120319042872, 0.0));
#110 = IFCCARTESIANPOINT ((10.10120319042872, 0.365));
#115 = IFCCARTESIANPOINT ((0.0, 0.365));
#120 = IFCPOLYLINE ((#100, #105, #110, #115, #100));
#125 = IFCARBITRARYCLOSEDPROFILEDEF (.AREA., $, #120);
#145 = IFCAXIS2PLACEMENT3D (#130, #135, #140);
#150 = IFCEXTRUDEDAREASOLID (#125, #145, #135, 2.7);
#155 = IFCSHAPEREPRESENTATION (#90, 'Body', 'SweptSolid', (#150));
#160 = IFCBOUNDINGBOX (#130, 10.10120319042872, 0.365, 2.7);
#170 = IFCSHAPEREPRESENTATION (#165, '', 'BoundingBox', (#160));
#175 = IFCMATERIALLAYERSET ((#70), 'Gips');
#180 = IFCMATERIALLAYERSETUSAGE (#175, .AXIS2., .POSITIVE., 0.0);
#195 = IFCRELASSOCIATESMATERIAL ('3TCnUKl5vFsABjwY2SfLle', #190, $, $, (#185), #180);
#200 = IFCCARTESIANPOINT ((1.05, 1.110223024625157E-16));
#205 = IFCDIRECTION ((1.0, 0.0));
#210 = IFCAXIS2PLACEMENT2D (#200, #205);
#215 = IFCRECTANGLEPROFILEDEF (.AREA., $, #210, 2.1, 1.0);
#220 = IFCDIRECTION ((0.0, 1.0, 0.0));
#225 = IFCAXIS2PLACEMENT3D (#130, #220, #135);
#230 = IFCEXTRUDEDAREASOLID (#215, #225, #135, 0.365);
#235 = IFCSHAPEREPRESENTATION (#90, 'Body', 'SweptSolid', (#230));
#245 = IFCRELVOIDSELEMENT ('2Az3wzJrL8Gw2L7sYQ2RS6', #190, $, $, #185, #240);
#250 = IFCCARTESIANPOINT ((1.0, 0.09999999999999998, -2.234906595725838E-17));
#255 = IFCCARTESIANPOINT ((1.0, -2.775557561562891E-17, -1.62260341881465E-17));
#260 = IFCCARTESIANPOINT ((0.95, 0.09999999999999998, -2.234906595725838E-17));
#265 = IFCCARTESIANPOINT ((0.95, -2.775557561562891E-17, -1.62260341881465E-17));
#270 = IFCCARTESIANPOINT ((0.95, 0.1000000000000001, 2.05));
#275 = IFCCARTESIANPOINT ((0.95, 9.71445146547012E-17, 2.05));
#280 = IFCCARTESIANPOINT ((0.04999999999999999, 0.1000000000000001, 2.05));
#285 = IFCCARTESIANPOINT ((0.04999999999999999, 9.71445146547012E-17, 2.05));
```

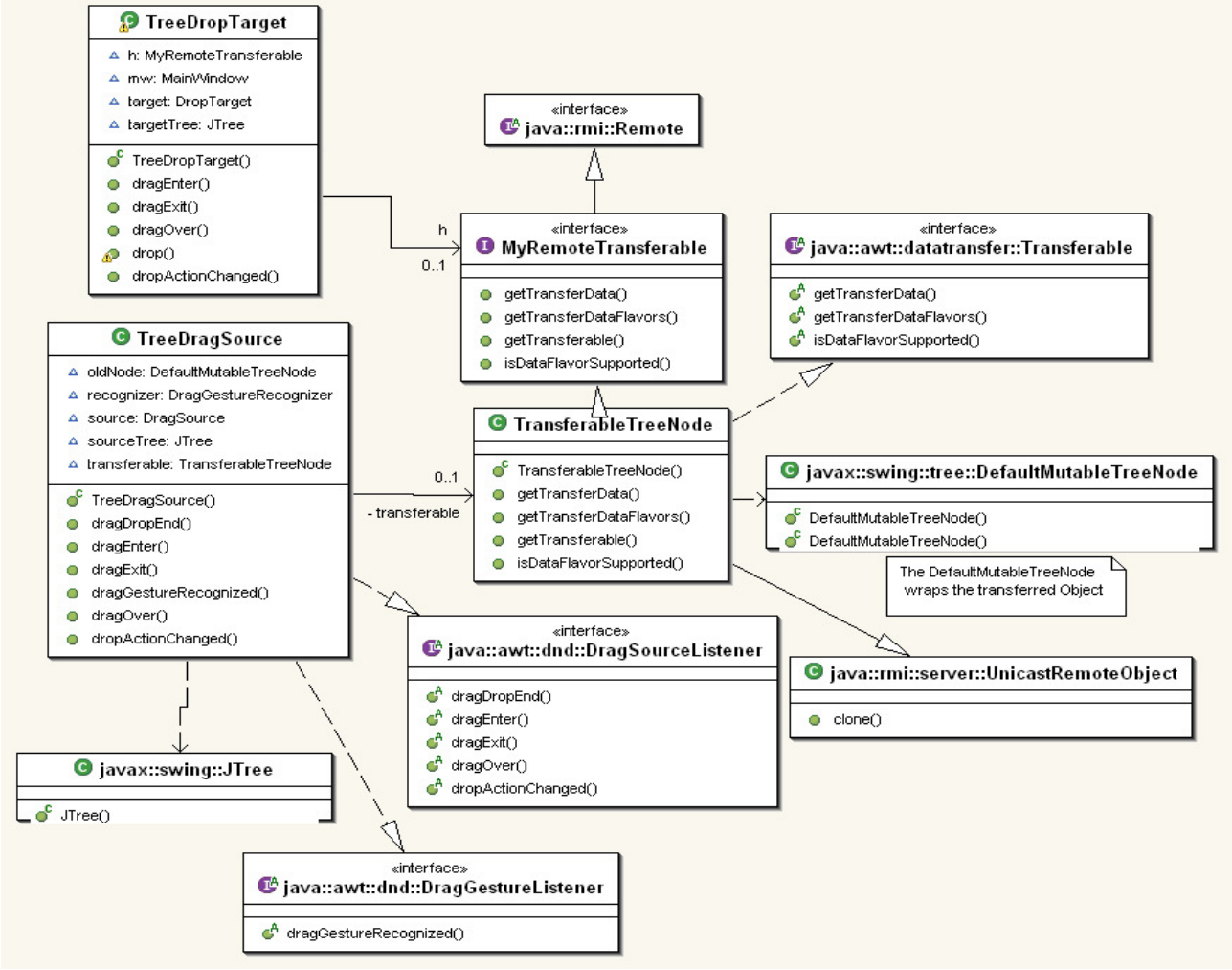
```
#290 = IFCCARTESIANPOINT ((0.04999999999999999, 0.09999999999999998, -2.234906595725838E-
17));
#295 = IFCCARTESIANPOINT ((0.04999999999999999, -2.775557561562891E-17,
-1.62260341881465E-17));
#300 = IFCCARTESIANPOINT ((0.0, 0.09999999999999998, -2.234906595725838E-17));
#305 = IFCCARTESIANPOINT ((0.0, 0.1000000000000001, 2.1));
#310 = IFCCARTESIANPOINT ((0.0, 9.71445146547012E-17, 2.1));
#315 = IFCCARTESIANPOINT ((1.0, 0.1000000000000001, 2.1));
#320 = IFCCARTESIANPOINT ((1.0, 9.71445146547012E-17, 2.1));
#325 = IFCCARTESIANPOINT ((0.04999999999999999, 0.05999999999999998, -1.989985324961363E-
17));
#330 = IFCCARTESIANPOINT ((0.04999999999999999, 0.0600000000000001, 2.05));
#335 = IFCCARTESIANPOINT ((0.95, 0.0600000000000001, 2.05));
#340 = IFCCARTESIANPOINT ((0.95, 0.05999999999999998, -1.989985324961363E-17));
#345 = IFCPOLYLOOP ((#250, #255, #265, #260));
#350 = IFCFACEOUTERBOUND (#345, .T.);
#355 = IFCFACE ((#350));
#360 = IFCPOLYLOOP ((#260, #265, #275, #270));
#365 = IFCFACEOUTERBOUND (#360, .T.);
#370 = IFCFACE ((#365));
#375 = IFCPOLYLOOP ((#270, #275, #285, #280));
#380 = IFCFACEOUTERBOUND (#375, .T.);
#385 = IFCFACE ((#380));
#390 = IFCPOLYLOOP ((#280, #285, #295, #290));
#395 = IFCFACEOUTERBOUND (#390, .T.);
#400 = IFCFACE ((#395));
#405 = IFCPOLYLOOP ((#290, #295, #130, #300));
#410 = IFCFACEOUTERBOUND (#405, .T.);
#415 = IFCFACE ((#410));
#420 = IFCPOLYLOOP ((#300, #130, #310, #305));
#425 = IFCFACEOUTERBOUND (#420, .T.);
#430 = IFCFACE ((#425));
#435 = IFCPOLYLOOP ((#305, #310, #320, #315));
#440 = IFCFACEOUTERBOUND (#435, .T.);
#445 = IFCFACE ((#440));
#450 = IFCPOLYLOOP ((#315, #320, #255, #250));
#455 = IFCFACEOUTERBOUND (#450, .T.);
#460 = IFCFACE ((#455));
#465 = IFCPOLYLOOP ((#250, #260, #270, #280, #290, #300, #305, #315));
#470 = IFCFACEOUTERBOUND (#465, .T.);
#475 = IFCFACE ((#470));
#480 = IFCPOLYLOOP ((#255, #320, #310, #130, #295, #285, #275, #265));
#485 = IFCFACEOUTERBOUND (#480, .T.);
#490 = IFCFACE ((#485));
#495 = IFCCLOSEDSHELL ((#355, #370, #385, #400, #415, #430, #445, #460, #475, #490));
#500 = IFCFACETEDBREP (#495);
#505 = IFCPOLYLOOP ((#290, #325, #330, #280));
#510 = IFCFACEOUTERBOUND (#505, .T.);
#515 = IFCFACE ((#510));
#520 = IFCPOLYLOOP ((#280, #330, #335, #270));
#525 = IFCFACEOUTERBOUND (#520, .T.);
#530 = IFCFACE ((#525));
#535 = IFCPOLYLOOP ((#270, #335, #340, #260));
#540 = IFCFACEOUTERBOUND (#535, .T.);
#545 = IFCFACE ((#540));
#550 = IFCPOLYLOOP ((#260, #340, #325, #290));
#555 = IFCFACEOUTERBOUND (#550, .T.);
#560 = IFCFACE ((#555));
#565 = IFCPOLYLOOP ((#290, #280, #270, #260));
#570 = IFCFACEOUTERBOUND (#565, .T.);
#575 = IFCFACE ((#570));
#580 = IFCPOLYLOOP ((#325, #340, #335, #330));
#585 = IFCFACEOUTERBOUND (#580, .T.);
#590 = IFCFACE ((#585));
#595 = IFCCLOSEDSHELL ((#515, #530, #545, #560, #575, #590));
#600 = IFCFACETEDBREP (#595);
#605 = IFCSHAPEREPRESENTATION (#90, 'Body', 'Brep', (#500, #600));
#130 = IFCCARTESIANPOINT ((0.0, 0.0, 0.0));
#610 = IFCBOUNDINGBOX (#130, 1.0, 0.1000000000000001, 2.1);
```

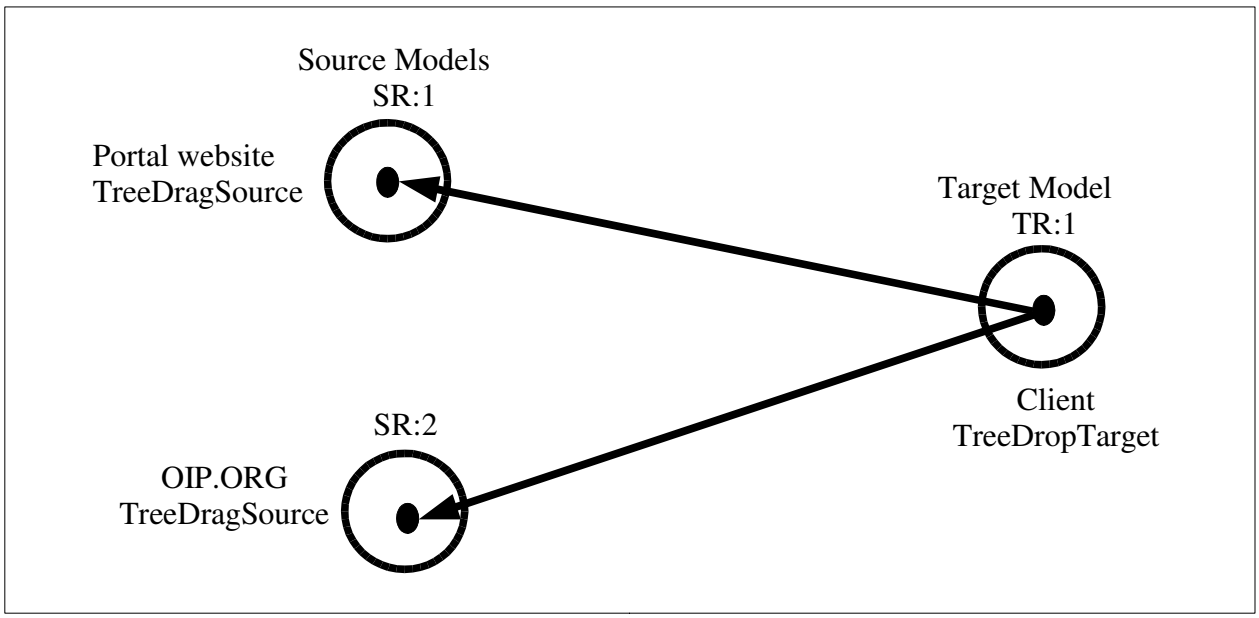
```
#135 = IFCDIRECTION ((0.0, 0.0, 1.0));
#140 = IFCDIRECTION ((1.0, 0.0, 0.0));
#615 = IFCAXIS2PLACEMENT3D (#130, #135, #140);
#90 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Design', 3, 1.0E-5, #615, $);
#165 = IFCGEOMETRICREPRESENTATIONCONTEXT ('Plan', 'Sketch', 3, 1.0E-5, #615, $);
#620 = IFCSHAPEREPRESENTATION (#165, '', 'BoundingBox', (#610));
#625 = IFCCARTESIANPOINT ((3.465191904287138, 0.0, 0.0));
#630 = IFCAXIS2PLACEMENT3D (#625, #135, #140);
#640 = IFCLOCALPLACEMENT (#635, #630);
#645 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#235));
#240 = IFCOPENINGELEMENT ('0S5L_BYhL9HA$DiCBs_2sA', #190, $, $, $, #640, #645, $);
#655 = IFCRELFILLSELEMENT ('3mzNgIau1ASutjmkUxrjkk', #190, $, $, #240, #650);
#660 = IFCDOORLININGPROPERTIES ('1Dk_90R91FCPwTTDLdBFjz', #190, $, $, 0.1, 0.05, $, $, $,
$, $, $, $, $, $);
#665 = IFCDOORPANELPROPERTIES ('3Cx5MviDz3jvI97hgKs7dz', #190, $, $, 0.04, .SWINGING.,
1.0, .MIDDLE., $);
#670 = IFCDOORSTYLE ('22pPa5fu13r98s6EWYiKfX', #190, $, $, $, (#660, #665), $, $, .
SINGLE_SWING_LEFT., .ALUMINIUM., .F., .F.);
#680 = IFCRELDEFINESBYTYPE ('OIP_02e66cedd', #190, 'OIP4', 'type_definition', (#650),
#675);
#685 = IFCPROPERTYSINGLEVALUE ('INFO', $, IFCDESCRIPTIVEMEASURE (''), $);
#690 = IFCPROPERTYSINGLEVALUE ('REVEAL', $, IFCINTEGER (0), $);
#695 = IFCPROPERTYSINGLEVALUE ('HEAD DEPTH', $, IFCNUMERICMEASURE (0.), $);
#700 = IFCPROPERTYSINGLEVALUE ('SILL DEPTH', $, IFCNUMERICMEASURE (0.), $);
#705 = IFCPROPERTYSINGLEVALUE ('JAMB DEPTH', $, IFCNUMERICMEASURE (0.), $);
#710 = IFCPROPERTYSINGLEVALUE ('JAMB DEPTH 2', $, IFCNUMERICMEASURE (0.), $);
#715 = IFCPROPERTYSINGLEVALUE ('HINGE AT START', $, IFCINTEGER (0), $);
#720 = IFCPROPERTYSINGLEVALUE ('SWING TO INTERIOR', $, IFCINTEGER (0), $);
#725 = IFCPROPERTYSINGLEVALUE ('REFSIDE', $, IFCINTEGER (0), $);
#730 = IFCCOMPLEXPROPERTY ('DOOR', $, 'ArchiCAD', (#685, #690, #695, #700, #705, #710,
#715, #720, #725));
#735 = IFCCARTESIANPOINT ((-0.5, 0.265, 0.0));
#740 = IFCAXIS2PLACEMENT3D (#735, #135, #140);
#745 = IFCLOCALPLACEMENT (#640, #740);
#750 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#605, #620));
#650 = IFCDOOR ('2XRBG6KUPCABBepxeXZZpe', #190, 'T\X\FCr-004', $, $, #745, #750, $, 2.1,
1.0);
#760 = IFCRELDEFINESBYPROPERTIES ('2MA2MMI9T71RiUrdhxEUpK', #190, 'ArchiCAD',
'ExtendedProperties', (#650), #755);
#755 = IFCPROPERTYSET ('3OwdtkyV10dBOpKTH2ofe8', #190, 'Graphisoft AC70 DOOR', 'Graphisoft
AC70', (#730));
#770 = IFCRELDEFINESBYPROPERTIES ('3uvUkwGvLD5B69Kb12VESL', #190, $, $, (#650), #765);
#765 = IFCPROPERTYSET ('15OYbYFhj8_R1rBQ_bAdAQ', #190, 'Pset_DoorCommon', $, (#775, #780,
#785));
#775 = IFCPROPERTYSINGLEVALUE ('Reference', $, IFCIDENTIFIER ('re'), $);
#780 = IFCPROPERTYSINGLEVALUE ('Description', $, IFCLABEL ('d'), $);
#785 = IFCPROPERTYSINGLEVALUE ('IsExterior', $, IFCBOOLEAN (.T.), $);
#790 = IFCPROPERTYSINGLEVALUE ('LAYERNAME', $, IFCDESCRIPTIVEMEASURE
('Au\X\DFenw\X\E4nde'), $);
#795 = IFCPROPERTYSINGLEVALUE ('INFO', $, IFCDESCRIPTIVEMEASURE ('Wand-006'), $);
#800 = IFCPROPERTYSINGLEVALUE ('REFMATNAME', $, IFCDESCRIPTIVEMEASURE ('Verputz,
wei\X\DF'), $);
#805 = IFCPROPERTYSINGLEVALUE ('SIDEMATNAME', $, IFCDESCRIPTIVEMEASURE ('Verputz,
wei\X\DF'), $);
#810 = IFCPROPERTYSINGLEVALUE ('OPPMATNAME', $, IFCDESCRIPTIVEMEASURE ('Verputz,
wei\X\DF'), $);
#815 = IFCPROPERTYSINGLEVALUE ('WALL CONTPEN', $, IFCDESCRIPTIVEMEASURE ('Pen4'), $);
#820 = IFCPROPERTYSINGLEVALUE ('WALL CONTLTYPE', $, IFCDESCRIPTIVEMEASURE ('Vollinie'),
$);
#825 = IFCPROPERTYSINGLEVALUE ('WALL CONTPEN3D', $, IFCDESCRIPTIVEMEASURE ('Pen2'), $);
#830 = IFCPROPERTYSINGLEVALUE ('WALL FILLPEN', $, IFCDESCRIPTIVEMEASURE ('Pen2'), $);
#835 = IFCPROPERTYSINGLEVALUE ('WALL FILLBGPEN', $, IFCDESCRIPTIVEMEASURE ('Missing Pen
(0)'), $);
#840 = IFCPROPERTYSINGLEVALUE ('WALL USECOMPPENS', $, IFCINTEGER (0), $);
#845 = IFCPROPERTYSINGLEVALUE ('WALL USECOMPBGPEN', $, IFCINTEGER (0), $);
#850 = IFCCOMPLEXPROPERTY ('WALL', $, 'ArchiCAD', (#790, #795, #800, #805, #810, #815,
#820, #825, #830, #835, #840, #845));
#855 = IFCPROPERTYSET ('2uuQAfrmz0veWuL3Hm$CCN', #190, 'Graphisoft AC70 WALL', 'Graphisoft
AC70', (#850));
```

```
#860 = IFCRELDEFINESBYPROPERTIES ('1j262uvyjBRw1t1e02cX3A', #190, 'ArchiCAD',
'ExtendedProperties', (#185), #855);
#865 = IFCAXIS2PLACEMENT3D (#130, #135, #140);
#875 = IFCLOCALPLACEMENT (#870, #865);
#880 = IFCCARTESIANPOINT ((-0.07009872382851423, -0.1156536989032908, 0.0));
#885 = IFCAXIS2PLACEMENT3D (#880, #135, #140);
#635 = IFCLOCALPLACEMENT (#875, #885);
#890 = IFCPRODUCTDEFINITIONSHAPE ($, $, (#95, #155, #170));
#185 = IFCWALLSTANDARDCASE ('0ut41YbU54kw92AmTHWCZp', #190, 'Wand-006', $, $, #635, #890,
$);
#895 = IFCPERSON ($, 'Undefined', $, $, $, $, $, $);
#900 = IFCORGANIZATION ($, 'OrganizationName', $, $, $);
#905 = IFCPERSONANDORGANIZATION (#895, #900, $);
#910 = IFCORGANIZATION ('GS', 'Graphisoft', 'Graphisoft', $, $);
#915 = IFCAPPLICATION (#910, '7.0', 'ArchiCAD 7.0', 'ArchiCAD');
#190 = IFCOWNERHISTORY (#905, #915, $, .NOCHANGE., $, $, $, 1107858490);
#920 = IFCBUILDINGSTOREY ('2syKlroGT6g8FlqdPqUKPX', #190, '', $, $, #875, $, '', .
ELEMENT., 0.0);
#925 = IFCRELCONTAINEDINSPATIALSTRUCTURE ('1GFqluQ6PFmQyJGwat8x8o', #190,
'BuildingStoreyContainer', 'BuildingStoreyContainer for Building Elements', (#185, #650),
#920);
#870 = IFCLOCALPLACEMENT (#930, #615);
#935 = IFCBUILDING ('1VM5_lKOHA6fYkaj5TxbPh', #190, 'Default Building', $, $, #870, $,
$, .ELEMENT., $, $, $);
#940 = IFCRELAGGREGATES ('3FCllzafP1Xg1J$9qE9CTz', #190, 'BuildingContainer',
'BuildingContainer for BuildigStories', #935, (#920));
#930 = IFCLOCALPLACEMENT ($, #615);
#945 = IFCSITE ('2w3KdbWpr0rgqF8_D1QOtI', #190, 'Default Site', $, $, #930, $, $, .
ELEMENT., $, $, $, $, $);
#950 = IFCRELAGGREGATES ('2oBFYAeffFwuZzYCV9hdwX', #190, 'SiteContainer', 'SiteContainer
For Buildings', #945, (#935));
#955 = IFCUNITASSIGNMENT ((#5, #10, #15, #35, #40, #45, #50, #55, #60));
#960 = IFCPROJECT ('2PwqLnSQPEkRKQO_v5W8ft', #190, 'Default Project', $, $, $, $, (#90,
#165), #955);
#965 = IFCRELAGGREGATES ('3sBDTHViPCRQI0LSI5w0Sq', #190, 'ProjectContainer',
'ProjectContainer for Sites', #960, (#945));
#970 = IFCPROPERTYSINGLEVALUE ('Country Of Origin', 'The origin of the product', IFCLABEL
('GER'), $);
#975 = IFCPROPERTYSINGLEVALUE ('Brand Name', 'The Brand Name of the Product', IFCLABEL
('BAB'), $);
#980 = IFCPROPERTYSINGLEVALUE ('List Price', 'The List Price of the Door',
IFCMONETARYMEASURE (1222.00), $);
#985 = IFCPROPERTYSINGLEVALUE ('Availability', 'The availability of the Product',
IFCBOOLEAN (.T.), $);
#990 = IFCPROPERTYSET ('OIP_01d1b2067', #190, 'Pset_DoorCommercial',
'Pset_DoorCommercial', (#970, #975, #980, #985));
#995 = IfcRelDefinesByProperties ('OIP_01d1b2067', #190, 'Pset_DoorCommercial',
'Pset_DoorCommercial', (#650), #990);
#675 = IFCDOORSTYLE ('OIP_02e66cedd', #190, $, $, $, $, $, $, .SINGLE_SWING_RIGHT., .
STEEL., .F., .F.);
#1000 = IFCCLASSIFICATIONNOTATIONFACET ('ISO9000');
#1005 = IFCCLASSIFICATIONNOTATION ((#1000));
#1010 = IFCRELASSOCIATESCLASSIFICATION ('OIP_01393c32a', #190, 'OIP4', 'classification',
(#650), #1005);
#1020 = IFCMATERIALLIST ((#1015));
#1025 = IFCPROPERTYREFERENCEVALUE ('Materal for a product', 'description', 'OIP', #1020);
#1030 = IFCPROPERTYSET ('OIP_02ff2541b', #190, 'External References to Materials',
'Description', (#1025));
#1035 = IFCRELDEFINESBYPROPERTIES ('OIP_02ff2541b', #190, 'Relating material to product',
'description', (#185), #1030);
#1040 = IFCPROPERTYSINGLEVALUE ('Length', $, IFCREAL (0.21), $);
#1015 = IFCMATERIAL ('02053d636  ---> Material: BRICK');
#1065 = IFCEXTENDEDMATERIALPROPERTIES (#1015, (#1040, #1045, #1050, #1055, #1060),
'Relating property to material', 'Name');
#1045 = IFCPROPERTYSINGLEVALUE ('Height', $, IFCREAL (0.075), $);
#1050 = IFCPROPERTYREFERENCEVALUE ('Constituent for a Material', 'description', 'OIP',
#1070);
#1070 = IFCMATERIALLIST ((#1075, #1080, #1085));
#1075 = IFCMATERIAL ('03a954388 ---> Material: GRAVEL');
```

```
#1080 = IFCMATERIAL ('02f4c5ce9 ---> Material: SAND');
#1055 = IFCPROPERTYSINGLEVALUE ('Density', $, IFCREAL (1500), $);
#1060 = IFCPROPERTYSINGLEVALUE ('width', $, IFCREAL (0.15), $);
#1090 = IFCPROPERTYSINGLEVALUE ('Density', $, IFCREAL (1.3), $);
#1085 = IFCMATERIAL ('039f04613 ---> Material: SAND');
#1095 = IFCEXTENDEDMATERIALPROPERTIES (#1085, (#1090), 'Relating property to material',
'Name');
#1100 = IFCCLASSIFICATIONNOTATIONFACET ('ISO10000');
#1105 = IFCCLASSIFICATIONNOTATION ((#1100));
#1110 = IFCMATERIALCLASSIFICATIONRELATIONSHIP ((#1105), #1085);
ENDSEC;
END-ISO-10303-21;
```

Appendix B: The use of a Drag and Drop solution over the Internet for the merging and transfer of data.





Transfer and Merging of information over the Internet by RMI and DnD

Appendix "C"

Attached to the back cover of this thesis is a CD-ROM containing the following:

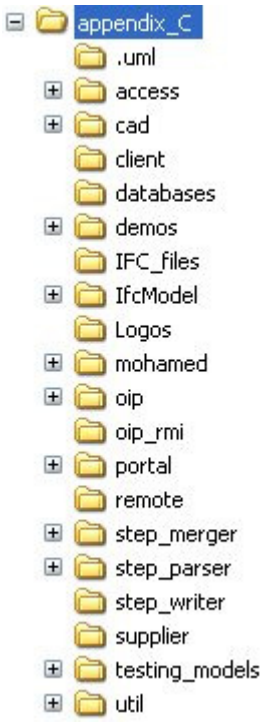
1- The Java IFC2x Model (early and late binding classes).

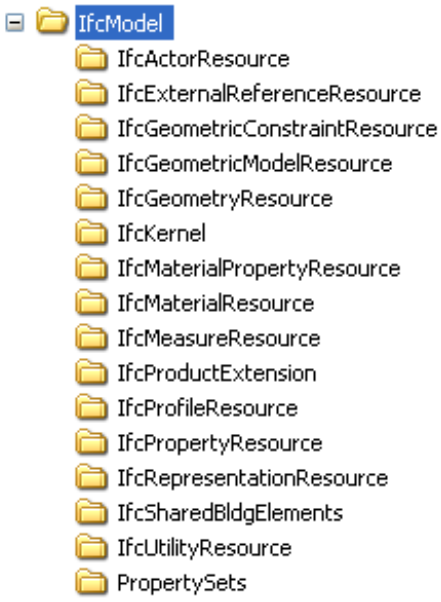
2- The Java coding of the developed software tools.

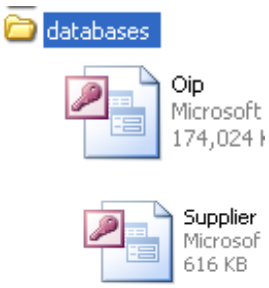
3- Databases.

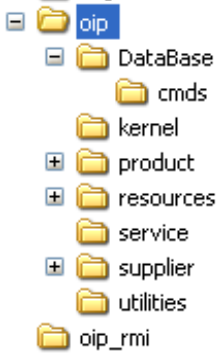
4- Testing IFC/CAD models for the Prototype Implementation.

5- Video demonstrations for the operations supported by the developed software tools.









Zusammenfassung

Die vorliegende Dissertation stellt ein flexibles und dynamisches Gebäudeinformationsmodell vor, mit dem die Produktinformationen der Bauteile erfragt und aktualisiert werden können. Dazu werden Beziehungen zwischen den Bauteilen im Gebäudeinformationsmodell und den Produktinformationen der Hersteller und Lieferanten definiert. Die Produktinformationen können über eindeutige Produktnamen und über verallgemeinerte Produktparameter identifiziert werden.

Der Stand der Technik bei den digitalen Bauteilkatalogen besteht überwiegend in einer Beschreibung der Produkte in Dokumenten im HTML- oder PDF-Format. Diese Dokumente können mit Hilfe von Schlüsselwörtern durchsucht werden. Hierbei besteht das Problem, dass die Produktinformationen nicht dauerhaft den Objekten im Gebäudeinformationsmodell zuzuordnen sind. Demzufolge kann verfügbare CAD-Software die verwendeten Produkte der Bauteile nicht vollständig beschreiben. Da viele Prozesse aktuelle Informationen der Bauteilprodukte benötigen, ist eine Erweiterung vorhandener Gebäudeinformationsmodelle um diesen Aspekt erforderlich. Obwohl dies Gegenstand zahlreicher proprietärer Entwicklungen ist, ist der Austausch von Daten infolge fehlender Standardisierung nicht ohne Informationsverluste möglich. Diesem Thema widmen sich derzeit unabhängige Forschungsprojekte, in denen neue Taxonomien und Ontologien für die Beschreibung der Semantik von Bauteildaten auf Basis von XML entwickelt werden. Diese Lösungsansätze haben den Nachteil, dass die Produktinformationen der Hersteller und Lieferanten notwendigerweise in einer gemeinsamen Datenbasis gespeichert werden müssen.

Die Untersuchung des Lebenszyklus von Bauwerken im Hinblick auf die Wertschöpfungskette und die Beschaffungskette ergab, dass die Informationen sowohl der Bauteile als auch der Produkte über die gesamte Lebensdauer des Bauwerks verfügbar sein müssen. Aus kaufmännischer Sicht besteht das Problem, dass die Produkte eines Herstellers unter verschiedenen Markennamen angeboten und verkauft werden. Untersuchungen haben gezeigt, dass der Markenname ein wesentlicher Faktor einer Marktstrategie ist. Auch die Zwischenhändler spielen hierbei eine wichtige Rolle – selbst dann, wenn die Geschäfte über das Internet abgewickelt werden. Bauteile haben die Besonderheit, dass sie teilweise oder ganz auf der Baustelle hergestellt werden. Dies muss bei der Konzeption eines Informationssystems, das sich mit der Wertschöpfungskette von Bauwerken befasst, beachtet werden.

Eine Erkenntnis der vorliegenden Arbeit ist, dass eine parametrisierte Produktsuche nur möglich ist, wenn die Produkte eindeutige Namen und standardisierte Parameter besitzen. Dieser Lösungsansatz könnte die derzeitige Arbeitsweise in der Praxis ändern. Für die prototypische Umsetzung im Rahmen der Dissertation hat sich eine Abstützung auf das verfügbare IFC-Modell als besonders geeignet erwiesen, da dieses Modell nicht-proprietär, fachübergreifend sowie durch Eigenschaften erweiterbar ist.

Der Kerngedanke des vorgestellten Lösungskonzepts besteht in der Entwicklung des OIP-Konzepts (Object Information Pack), welches eine dauerhafte und dynamische Datenquelle für Gebäudeinformationsmodelle behandelt. Die OIP ist nicht nur ein eindeutiger Produktname, sondern eine ganze Datenstruktur für Produktinformationen im Bauwesen. Die OIP besteht aus einer dreischichtigen Hierarchie, welche sich sowohl in der Struktur der Datenbasis als auch in der Struktur der Klassen widerspiegelt. Diese Struktur wird über eine Gruppe von Relationen vom OIP-Kern verwaltet. Das Format der OIP-Namen sowie die Verteilung der Daten zwischen den Beteiligten (produktunabhängige technische Daten und produktabhängige Daten der Lieferanten) sind die wesentlichen Neuerungen gegenüber den bekannten Ansätzen mit einer zentralen Datenbasis. Das in dieser Arbeit vorgestellte Lösungskonzept basiert auf einer eingehenden Betrachtung und Analyse der Beschaffungskette von Bauwerken unter Beachtung der Besonderheiten des Bauwesens.

Es hat sich herausgestellt, dass das OIP-Konzept allein nicht ausreicht, um eine Brücke zwischen den Daten der Hersteller und Händler auf der einen und dem Kunden auf der anderen Seite zu schlagen. Darüber hinaus wurde eine integrierte Softwarelösung für die Umsetzung des Konzepts benötigt, die zum Zeitpunkt des Entstehens dieser Dissertation nicht verfügbar war. Daher hat der Autor Werkzeuge mit folgender Funktionalität entwickelt:

- Parsen von STEP-ISO-10303-P21-Dateien
- Interpretation der geparsten Daten in IFC2x-Java-Klassen
- Abbildung und Integration von Produktdaten in das IFC-Modell
- Instanziierung, Löschen und Änderung von Objekten
- Definition von Suchparametern durch den Anwender
- Extraktion von Suchparametern aus dem CAD/IFC-Model
- Durchführen von parametrisierten Suchen
- Bereitstellung verschiedener Arten der Visualisierung des IFC Modells
- Export des modifizierten IFC-Modells in Form einer STEP-P21-Datei

Mit diesen Werkzeugen konnte das Konzept der Arbeit verifiziert werden. Aufgrund ihres flexiblen Entwurfs können diese Werkzeuge darüber hinaus auch bei anderen Problemstellungen im Zusammenhang mit dem IFC-Modell verwendet werden. Es handelt sich nämlich um einfache Werkzeuge, die eine Integration des IFC-Modells in andere Applikationen ermöglichen.

Die Einführung des Konzepts in die Praxis erfordert die Verwaltung durch eine eigene Organisation. Die Rolle dieser OIP-Organisation und das Internetportal der Hersteller wurden ebenfalls innerhalb einer verteilten Applikation simuliert. Zur übersichtlichen Darstellung der Ergebnisse und zum Nachweis der Anwendbarkeit des Konzeptes wurden alle Werkzeuge mit einer graphischen Nutzeroberflächen ausgestattet.

Schließlich möchte der Autor betonen, dass eine Übernahme eines solchen „Business Process Re-engeneering“ (BPR) Konzeptes in die industrielle Praxis nicht frei von Barrieren und Problemen ist. Aus der Literatur über Firmenkultur und Psychologie ist bekannt, dass Nutzer oft ablehnend auf die Einführung neuer Systeme reagieren, wenn diese die gewohnte Arbeitsweise in Frage stellen. Hierbei spielt es keine Rolle, ob das resultierende Ergebnis auf lange Sicht zu einer Optimierung und Reduzierung des Aufwands führt. Ein Wechsel der derzeitigen Praxis könnte jedoch erreicht werden, wenn einige innovative Unternehmen ihren Anwendern die Gelegenheit gäben, sich von den Vorteilen der neuen Arbeitsweise zu überzeugen.